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" " Pt. 2—(To be issued sometime during 1937)		5.00
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PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME LXXVI

1936

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
1936

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DURING 1936

Stated Meeting, January 3, 1936

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

The decease of the following members was announced:

Edwin Wilbur Rice, Jr., A.M., Sc.D., D.Eng., at Schenectady, on November 25, 1935, æt. 73.

Lafayette B. Mendel, Ph.D., Sc.D., LL.D., at New Haven, on December 9, 1935, æt. 63.

Howard McClenahan, E.E., Litt.D., D.Sc., LL.D., in Florida, December 17, 1935, æt. 63.

Arno Viehoever, Director of the Biological and Biochemical Research Laboratory of the Philadelphia College of Pharmacy and Science, read a paper on "Daphnia, the Living Reagent," which was illustrated with living organisms, lantern slides and motion pictures.

Edward P. Cheyney was elected a Councillor to fill the vacancy caused by Gustavus Wynne Cook's inability to serve.

Stated Meeting, February 7, 1936

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

The decease of the following members was announced:

Frederick Leslie Ransome, Ph.D., at California, October 6, 1935, æt. 67.

Richard T. Glazebrook, F.R.S., at Limpsfield, Surrey, England, December 15, 1935, æt. 81.

William B. Scott, Ph.D., Sc.D., LL.D., Professor Emeritus of Geology, Princeton University, read a paper on "The

Astrapotheria, Extinct Monsters of the Patagonian Tertiary" which was illustrated with lantern slides. The paper was discussed by Dr. Gregory and Dr. Winsor, a guest.

The following paper was read by title:

"Circular Cylinders. II," E. P. Adams, Princeton University.

Stated Meeting, March 6, 1936

Albert P. Brubaker, A.M., M.D., LL.D., in the Chair.

The Committee on Nomination of Officers made its report.

The decease of the following member was announced:

George D. Rosengarten, B.S., Ph.D., Sc.D., at Philadelphia, February 24, 1936, æt. 67.

Annual General Meeting, April 23, 24, 25, 1936
Thursday Morning, April 23
Opening Session, 10 o'clock

Roland S. Morris, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

Roger Adams, Paul D. Foote, Yandell Henderson and F. K. Richtmyer, recently elected members, subscribed the Laws and were admitted into the Society.

The following papers were read:

"Resuscitation with Carbon Dioxide," Yandell Henderson, Professor of Physiology, Yale University. The paper was discussed by Dr. Schaeffer.

"The Mechanism and Pathology of Shock," Virgil H. Moon, Professor of Pathology, Jefferson Medical College. (Introduced by Dr. Schaeffer.)

"Inheritance of a Sharply Localized Paralysis in the Dog Resembling Certain Paralyses of Man," Charles R. Stockard, Professor of Anatomy, Cornell University Medical College.

"Some Factors Which Modify the Permeability of the

Red Blood-cell," Merkel H. Jacobs, Professor of General Physiology, University of Pennsylvania.

Special Meeting, 12 o'clock
In Celebration of Shakespeare's Birthday

Gilbert Chinard, B.L., L.èsL., in the Chair

The speakers were introduced by Dr. Schelling.

"A Brief Report on the Progress of the Shakespeare Variorum."

"Shakespeare's 17th Century Editors," Matthew W. Black, University of Pennsylvania. The papers were discussed by Mr. H. S. Morris.

"Shakespeare in Philadelphia," Henry N. Paul, Dean, Shakspeare Society of Philadelphia.

Thursday Afternoon, 2 o'clock

Edwin G. Conklin, Ph.D., Sc.D., LL.D., Vice-president, in the Chair

The following papers were read:

"Dedifferentiation and Redifferentiation of the Fibrillar Neuromotor System of Ciliates during Asexual and Sexual Reproduction," Charles A. Kofoid, Professor of Zoology, University of California, and Datus M. Hammond. (Read by title.)

"The Comparative Metabolism of Rats Fed on Sucrose and Glucose Respectively," John R. Murlin, Professor of Physiology, and Director, Department of Vital Economics, University of Rochester, W. R. Murlin, W. M. Barrows, Jr., and Pauline Nutter.

"The Heart Rate of the Elephant," Francis G. Benedict, Director, Nutrition Laboratory, Carnegie Institution of Washington, Boston, and Robert C. Lee. (Read by title.)

"Palisot de Beauvois, an Overlooked American Botanist," Elmer D. Merrill, Gray Herbarium, Harvard

University. Discussed by Dr. Chinard and two guests.

"Thomas Jefferson's Garden Diary," Rodney H. True, Director, Morris Arboretum, University of Pennsylvania.

"Living Plants as Indicators of Geological History," Merritt L. Fernald, Fisher Professor of Natural History, Harvard University, and Curator, Gray Herbarium. (Introduced by Dr. True.) Discussed by Dr. Berry.

"The Communication of the Pneumatic Systems of Trees with the Atmosphere." Daniel T. MacDougal, Desert Laboratory, Tucson, Arizona. (Read by title.)

"A New Method of Synthesizing Pure-breeding Types with Extra-chromosomal Material in *Datura*." Albert F. Blakeslee, Director, Department of Genetics, Carnegie Institution of Washington, Cold Sprir Harbor, A. Dorothy Bergner and Amos G. Avery by Drs. Berry and Davis.

"The Offspring of a Triploid Sporop Allen, Professor of Botany, Unive and Elizabeth Mackay. Dis and Blakeslee.

Friday Morning, Apri

Executive Session, 10 o'clo

ROLAND S. MORRIS, LL.B., LL.D., D.C.L
President, in the Chair

The President gave a report concerning the membership and made a brief statement about the Soc funds, the Wood Estate, the cancelling of the contract w the City, etc., which items are on file.

On motion the Finance Committee's action concerning the Wood Estate was unanimously approved.

The following resolution was adopted:

Resolved, That the President or Vice-president and any one of the Secretaries of The American Philosophical Society Held at Philadelphia for Promoting Useful Knowledge, be and are hereby authorized and empowered to execute and deliver in the name and on behalf of the Society, a power or powers of attorney, to enter satisfaction on the record of

(*A*) All those certain mortgages heretofore assigned to the Society by the respective holders thereof upon payment of the amount due thereon by or on behalf of the said Society, and secured upon certain real estate and premises devised to said Society in the Estate of Walter Wood, deceased, as appears by Schedule of Distribution filed in accordance with Adjudications of Klein, J., on August 9, 1935, and August 16, 1935, in the Orphans' Court of Philadelphia County, No. 1240 of 1935; (*B*) Any and all mortgages which may be held by ... ciety as an investment upon payment to the So... the amount due thereon; And to transfer any

The followi... olicies of fire and title insurance upon said

"Dedifferen... mises. Said Power of Attorney to be sub-

Neuromot... form presented to this meeting.

Sexual Rep. ...ion concerning the Wood Estate was

of Zo...logy, ...

H... mond.

"The Comp... n the Estate of Walter Wood, deceased, and Gl... ...ications of Klein, J., filed August 9 and fesso... , 1935, in the Orphans' Court of Philadelphia Vit... , No. 1240 of 1935, and Schedule of Distribution ... n accordance therewith, there were awarded to The "...erican Philosophical Society Held at Philadelphia for ...romoting Useful Knowledge certain assets of said Estate listed at inventory values, some of which assets were listed as of no value; and

WHEREAS, the Society has received from the Executors of said Estate possession of said assets so listed and/or

of certain documents in possession of the Executors evidencing the existence of said assets, except the following, viz.: *Millville Daily Republican* Publishing Company, 18 shares received instead of 20 shares thereof; $1,000, note of H. C. Gilmer included in said Schedule of Distribution in error, there being nothing due thereon; and

WHEREAS, upon investigation by the Committee on Finance of said Society certain of said assets have been finally determined to be of no value, and certain other of said assets upon further investigation by said Committee may be determined to be of no value, but the same have been received from the Executors of said Estate in compliance with the terms of the award thereof:

Now, be it resolved, that the Officers of the Society are hereby authorized and empowered to abandon and mark off as of no value said assets now or hereafter found by said Committee on Finance to be worthless and to eliminate the same from the books and/or inventories of the said Society relating to property owned by it;

Further resolved, that all acts and things done or performed by the Officers of the Society relating to the acceptance by the Society of the property and rights bequeathed or devised to it under the Will of Walter Wood, deceased, and all acts and proceedings which may in the judgment of said Officers be necessary to be done or performed in connection with the acceptance of said property and rights, including the payment and discharge of any taxes thereon, be and the same are hereby authorized, ratified, approved and confirmed.

Mr. Morris took up the matter of the contract with the City and stated that after negotiations and with the assistance of John M. Scott he had been able to have passed through City Council an Ordinance directing the Mayor to enter into another contract with the Society to abrogate the present contract.

The following resolution was presented:

Be it resolved, that The American Philosophical Society Held at Philadelphia for Promoting Useful Knowledge, by the President and a Secretary thereof acting on its behalf, enter into said further agreement or contract with the City of Philadelphia whereby said agreement between the City of Philadelphia and the Society, dated November 24, 1911, and recorded at Philadelphia in Deed Book J. M. H. No. 604, page 148, is wholly cancelled and annulled, to the same extent and with the same force and effect as though said agreement had never been entered into; and whereby the Society remises, releases and quitclaims unto the City of Philadelphia any and all right, titles and interest of, in, and to said plot of ground bounded by the Parkway, Sixteenth Street and Cherry Street as aforesaid; and whereby the Society releases and forever discharges said City of and from all claims and demands that the Society may now have, or heretofore have had or acquired, for or by reason of said agreement of November 24, 1911, or by virtue of the above mentioned Ordinances of Council of said City; and whereby said City releases and quitclaims to Society any and all right, title and interest which said City now has or may at any time have had by virtue of said agreement of November 24, 1911, or by virtue of any of the above mentioned Ordinances of Council of said City, in and to the lots or pieces of ground of said Society in the City of Philadelphia situate on the West side of Fifth Street, in the Fifth Ward of the City of Philadelphia, beginning ninety-six feet Southward from Chestnut Street; and whereby said City releases and discharges the Society of and from all claims and demands that it, the said City, may now have, or heretofore had had or acquired, for or by reason of said agreement of November 24, 1911, or by virtue of the above mentioned Ordinances of Council of said City;

And further resolved, that the form of said proposed agreement to be entered into between the City of Phila-

delphia by its Mayor as aforesaid, and The American Philosophical Society Held at Philadelphia for Promoting Useful Knowledge, to effectuate the foregoing, be and the same is hereby approved, and the President and a Secretary of the Society are authorized and directed, on its behalf, under its corporate seal, to enter into said agreement of the form, or substantially of the form, hereinabove referred to and made a part of the minutes of this meeting, and approved by counsel for the Society.

Mr. Morris asked to be authorized to complete these negotiations though it might necessitate the return of a substantial portion of the Building Fund to the contributors. On motion duly seconded the above resolution was adopted.

Mr. Morris stated that the Council had drafted Edwin G. Conklin to become the Executive Officer of the Society and further stated that he would also be Executive Vice-president.

Mr. Morris then presented a proposal of hereafter holding a second General Meeting of the Society in the Autumn to be primarily for reports on grants. He stated that a suggestion had been made that the meeting be held on Friday and Saturday succeeding Thanksgiving Day. It was on motion decided to hold a general meeting in the autumn on such a date as shall be determined by Council; all details to be left to Council.

The decease of the following members was announced:

Ivan Pavlov, February 27, 1936, æt. 87.

James M. Beck, at Washington, D. C., April 12, 1936, æt. 75.

The proceedings of the Council were submitted.

Dr. Conklin made a report on behalf of the Committee on Research which will be published.

Dr. Donaldson made a report for the Committee on Publication which is on file.

Dr. Sioussat made a brief report for the Committee on Library and stated that his regular report had already been published.

The purchase for $75,000 of the Bache Collection of Frankliniana which is now housed in the Library of the Society was again on motion approved.

The Society proceeded to an election of officers and members.

The tellers subsequently reported that the following officers and members had been duly elected:

President

Roland S. Morris

Vice-presidents

Edwin G. Conklin
Robert A. Millikan
Henry H. Donaldson

Secretaries

John A. Miller
William E. Lingelbach

Curator

Albert P. Brubaker

Councillors

(To serve for three years)
Max Farrand
Joseph Erlanger
George H. Parker
Marshall S. Morgan

Members

Residents of the United States

Newton Diehl Baker
Charles Austin Beard
Carl Becker
John Rogers Commons
Edward Samuel Corwin
Karl Kelc[illegible] Darrow

Charles Derleth, Jr.
William Edward Dodd
Merritt Lyndon Fernald
Cecilia Payne Gaposchkin
John Story Jenks
Arthur Becket Lamb
Lawrence J. Morris
Marston Morse
William Albert Nitze
Linus Carl Pauling
David Moore Robinson
Adolph H. Schultz
James Thomson Shotwell
George Gaylord Simpson
Alfred Henry Sturtevant
John Henry Wigmore
George Grafton Wilson
Robert Sessions Woodworth
Robert Mearns Yerkes

Foreign Residents

Peter Debye
Hu Shih
Thomas Garrigue Masaryk

The proposed revision of the Laws was discussed and upon motion, duly seconded, the proposed revision was unanimously approved, after minor amendments.

Morning Session, 11:45 o'clock

HENRY H. DONALDSON, A.B., Ph.D., Sc.D., Vice-president, in the Chair

Franklin Edgerton, recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Ionic Silver from Silver Hydroxide as a Therapeutic

Agent," John H. Müller, Professor of Chemistry, University of Pennsylvania. (Introduced by Dr. Donaldson.)

"Molecular Rotation in Solids," Charles P. Smyth, Associate Professor of Chemistry, Princeton University. Discussed by Dr. Andrews.

"Chemical Reactions Produced by Alpha-particles and Electrons," Hugh S. Taylor, Professor of Chemistry, Princeton University.

Friday Afternoon, 2 o'clock

Roland S. Morris, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

Edward S. Corwin, recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"The Deterioration of National Sovereignty," Edward S. Corwin, McCormick Professor of Jurisprudence, Princeton University. (Introduced by Dr. Lingelbach.) Discussed by President Morris and Dr. Em. R. Johnson.

"The Factors Controlling Prices," James W. Angell, Professor of Economics, Columbia University. (Introduced by Dr. Em. R. Johnson.) Discussed by Dr. Huntington.

"The Centenary of Tocqueville's Democracy in America," Gilbert Chinard, Professor of French and Comparative Literature, The Johns Hopkins University.

"Some Observations on Mark Twain," William Lyon Phelps, Professor Emeritus of English Literature, Yale University.

"Where is Franklin's First Map of the Gulf Stream?" Franklin Bache. (Introduced by Mr. Duane.)

"The Excavation of Antioch-on-the-Orontes," Charles R. Morey, Professor of Art and Archæology, Princeton University. (Introduced by Mr. Morris.)

"The Text of Acts in MS 146 of the Michigan Collection," Henry A. Sanders, Professor of Latin, University of Michigan, and Johanna Ogden.

"A Hindu Theory of Literary Æsthetics," Franklin Edgerton, Salisbury Professor of Sanskrit and Comparative Philology, Yale University. Discussed by President Morris and Dr. Phelps.

"Neolithic Sites on the Yugoslav Bank of the Lower Danube," Vladimir J. Fewkes, Director, Harvard-American School of Prehistoric Research. (Introduced by Dr. Barton.) (Read by title.)

"John Fitch, Inventor of the Steamboat, and The American Philosophical Society," Edward P. Cheyney, Professor Emeritus of History, University of Pennsylvania. (Read by title.)

Friday Evening, 8 o'clock

The R. A. F. Penrose, Jr., Memorial Lecture

Dixon Ryan Fox, President of Union College, spoke on *The American Tradition in a New Day.*

Saturday Morning, April 25

Morning session, 10 o'clock

William B. Scott, M.A., Ph.D., Sc.D., LL.D., in the Chair

Lawrence J. Morris, Merritt L. Fernald and Dixon Ryan Fox, recently elected members, subscribed the Laws and were admitted into the Society.

The following papers were read:

"A Taeniodont Skull from the Lower Eocene of Wyoming," C. L. Gazin, United States National Museum, Smithsonian Institution. (Introduced by Dr. Scott.) (Read by title.)

"A Study of the Oldest Known Vertebrates, *Astraspis* and *Eriptychius*," William L. Bryant, Director, Park Museum, Roger Williams Park, Providence, R. I. (Read by title.)

"The Millionth Map of Hispanic-America," Raye R. Platt, The American Geographical Society. (Introduced by Dr. Bowman.) Discussed by Drs. F. E. Wright and Bogert.

"The Geologists' Contribution to Public Safety," Charles P. Berkey, Professor of Geology, Columbia University. (Read by title.)

"New Light on the Supposed Meteorite Scars of the Carolina Coast," Douglas Johnson, Professor of Physiography, Columbia University.

"A Remarkable Case of a White River Cat Wounded in Life," William B. Scott, Professor Emeritus of Geology, Princeton University, and Glenn L. Jepsen.

"Habitus Factors in the Skeleton of Fossil and Recent Mammals," William K. Gregory, Curator, Department of Comparative and Human Anatomy, The American Museum of Natural History. Discussed by Dr. Scott.

"Early Man in America," Edgar B. Howard, University Museum, University of Pennsylvania. (Introduced by Dr. Conklin.)

"Prehistoric Man in Palestine," George Grant MacCurdy, Director, American School of Prehistoric Research.

"The Evidences of Growth in Different Parts of the Body after Adult Life has been Reached." Aleš Hrdlička, Curator, Division of Physical Anthropology, U[illegible] States National Museum, Smithsonian Institu[illegible]cussed by Dr. Cattell.

"The S[illegible]ver in Australia," Daniel S. Davidson, [illegible] Anthropology, University of Pennsyl-[illegible] (Introduced by Dr. Donaldson.) (Read by

Saturday Afternoon, 2 o'clock

Robert A. Millikan, A.B., Ph.D., Sc.D., LL.D.,
Vice-president, in the Chair

The following papers were read:

"Magnetic Formulæ Expressed in the M.K.S. System of Units," Arthur E. Kennelly, Professor Emeritus of Electrical Engineering, Harvard University. (Read by title.)

"The Split Cylindrical Condenser," Edwin P. Adams, Professor of Physics, Princeton University. (Read by title.)

"Effects at New High Pressures," Percy W. Bridgman, Hollis Professor of Mathematics and Natural Philosophy, Harvard University.

"Ball Lightning," William J. Humphreys, United States Weather Bureau, Washington, D. C. Discussed by Drs. Henderson, Abbot and Swann.

"Further Experiments on the Mass Analysis of the Chemical Elements," Arthur J. Dempster, Professor of Physics, University of Chicago. Discussed by Drs. Millikan and Briggs.

"Cosmic Ray Observation on the 1935 National Geographic United States Army Air Corps Stratosphere Flight," W. F. G. Swann, Director, Bartol Research Foundation of the Franklin Institute. Discussed by Drs. Millikan and A. H. Compton.

"Four Researches Bearing on the Metagalactic Problem," Harlow Shapley, Director, Harvard Observatory.

"McCormick Stellar Magnitudes," Samuel A. Mitchell, Director, Leander McCormick Observatory, University, Va.

"The Star Clouds of the Milky Way," Joel Stebbins, Director, Washburn Observatory, and Professor of Astronomy, University of Wisconsin, and Research Associate, Mt. Wilson Observatory, C. M. Huffer and A. E. Whitford. Discussed by Dr. Shapley.

Saturday Evening, 7:30 o'clock

The annual dinner was held at the Bellevue-Stratford.

Max Farrand, Director of Research of the Henry E. Huntington Library and Art Gallery, responded to the toast on Franklin in an address on *Franklin's Autobiography*.

Autumn General Meeting, November 27, 28, 1936
Friday Morning, November 27
Opening Session, 9 o'clock

EDWIN G. CONKLIN, Ph.D., Sc.D., LL.D.,
Vice-president, in the Chair

Robert M. Yerkes, recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Land Mollusks from Cozumel Island, Mexico, and Their Bearing on the Paleogeography of the Region," Horace G. Richards,* Research Associate, New Jersey State Museum. Discussed by Dr. Humphreys.

"Explorations in Northern Mexico for Mollusks in 1934–35," Henry A. Pilsbry,* The Academy of Natural Sciences of Philadelphia. Discussed by Drs. Conklin and Bumpus.

"Studies of Morphological Variations in the Intestinal Amœbæ of Man with Special Reference to the Nucleus," David H. Wenrich,* Professor of Zoology, University of Pennsylvania.

"Somatic Segregation in Relation to Atypical Growth," Donald F. Jones,* Connecticut Agricultural Experiment Station.

"Extra-chromosomal Influence on the Incidence of Tumors in Mice," Clarence C. Little,* Director, Roscoe B. Jackson Memorial Laboratory, Bar Harbor, Maine. Discussed by Drs. Parker, Jones and Cleland.

* Recipient of Grant from The Penrose Fund.

"Quantitative Studies of Radium Poisoning," Robley D. Evans,* Assistant Professor of Physics, Massachusetts Institute of Technology. Discussed by Dr. Conklin and Mr. H. S. Morris.

"Color Changes in Fishes and the Autonomic Nervous System," George H. Parker, Professor Emeritus of Zoology, Harvard University.

"Effect of Hemorrhage and Peptone Injections on Platelet Production in the Lungs," William H. Howell, Professor Emeritus of Physiology, The Johns Hopkins University. Discussed by Drs. Conklin and Parker.

"The Structure and Function of the Facial and the Labial Pits of Snakes," G. Kingsley Noble, American Museum of Natural History. Discussed by Drs. Scott, Yerkes, Conklin, Jones, Humphreys and Wenrich.

"The Rhinoceroses of the White River Oligocene," William B. Scott,* Professor Emeritus of Geology, Princeton University.

"Evolution of the Elasmotheres," Horace Elmer Wood, 2d,* Professor of Biology, University of Newark. (Read by title.)

Friday Afternoon, 2 o'clock

Roland S. Morris, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

Frank Albert Fetter, John Story Jenks, Alfred Vincent Kidder, G. Kingsley Noble, David Moore Robinson and George Gaylord Simpson, recently elected members, subscribed the Laws and were admitted into the Society.

The following papers were read:

"An Archæological Discovery in the Guatemala Highlands," Alfred V. Kidder, Division of Historical Research, Carnegie Institution of Washington. Discussed by Dr. Montgomery.

"Cenozoic Cycles in Asia and Their Bearing on Human Prehistory," Hellmut deTerra,* Research Associate, Carnegie Institution of Washington.

The President called on Vice-president Donaldson to take the Chair.

The following papers were read:

"Report on Linguistic and Cultural Studies among the Todas and Other Dravidian Peoples, 1935–36," Murray B. Emeneau,* Research Assistant, Yale University. (Read by Professor Franklin Edgerton.)

"Some Results of the Excavations at Olynthus," David M. Robinson, Professor of Archæology and Epigraphy, Lecturer in Greek Literature, The Johns Hopkins University. Discussed by Dr. Montgomery.

"The Excavation of Bethel," William F. Albright, Professor of Semitic Languages, The Johns Hopkins University.

"Results of a Search for Lost Greek Sculptures," William Bell Dinsmoor, Professor of Archæology, Columbia University.

"The Union Catalogue of the Philadelphia Metropolitan Area," Conyers Read,* Professor of English History, University of Pennsylvania.

Friday Evening, 8:15 o'clock

D'Arcy W. Thompson, Professor of Natural History, St. Andrews University, spoke on *Astronomy in the Classics.*

Saturday Morning, November 28

Executive Session, 9 o'clock

Roland S. Morris, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

Mr. Morris informed the Society that plans were being considered to clear of buildings the area in front of Independence Hall and eastward from Independence Square and

that he had been requested to call a meeting of its proponents at the Hall of the Society to organize a Committee to deal with this project. He added that he would not be Chairman of the Committee and that the Society would not be actively involved. On motion Mr. Morris was authorized to act in accordance with the above suggestion.

The decease of the following members was announced:

Arthur A. Noyes, Ph.D., Sc.D., LL.D., at Pasadena, June 3, 1936, æt. 70.
Ethelbert D. Warfield, A.M., LL.D., Litt.D., at Chambersburg, Pa., July 6, 1936, æt. 75.
Charles H. Frazier, B.A., M.D., Sc.D., at North Haven, Maine, July 26, 1936, æt. 66.
Alexandre Petrovitch Karpinsky, July 15, 1936, æt. 90.
Giuseppe Sergi, at Rome, Italy, October 17, 1936, æt. 95.
George Forbes, M.A., LL.D., F.R.S., October 22, 1936, æt. 87.
Eduard Meyer, Ph.D., LL.D., August 31, 1930, æt. 75.

Morning Session, 10 o'clock

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

The following papers were read:

"The Theory of Some Chemical Reactions," Henry Eyring,* Associate Professor of Chemistry, Princeton University.

"The Chemical Concentration of the Carbon Isotope," Harold C. Urey, Professor of Chemistry, Columbia University.

"Report on the Mass Analysis of the Chemical Elements," Arthur J. Dempster,* Professor of Physics, University of Chicago.

"The Design of Powerful Electromagnets," Francis Bitter,* Associate Professor of Physics of Metals,

Massachusetts Institute of Technology. Discussed by Dr. Abbot.

"The Nature of Cosmic Rays," W. F. G. Swann, Director, Bartol Research Foundation of the Franklin Institute.

"Impulse Methods for Ion Acceleration," Jesse W. Beams,* Professor of Physics, University of Virginia.

"Radioactive Measurement of Time and Difficulties," Alfred C. Lane,* Professor Emeritus of Geology and Mineralogy, Tufts College, Massachusetts. Discussed by Drs. Scott, Bitter and Dempster.

"The Verification of the Lunar Theory," Ernest W. Brown,* Professor Emeritus of Mathematics, Yale University, and W. J. Eckert. Discussed by Dr. Russell.

PUBLICATIONS

OF THE

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Volume I—General Analysis. Part I	Eliakim Hastings Moore	$3.00
Volume II—Roman Alpine Routes	Walter Woodburn Hyde	3.00
Volume III—Manus Religion	R. F. Fortune	3.00
Volume IV—The Ras Shamra Mythological Texts	James A. Montgomery and Zellig S. Harris	3.00 (educational discount allowed)

TRANSACTIONS

		Price per volume
Volume XXIV, Pt. 1—A New Marsupial Sabertooth from the Pliocene of Argentina and its Relationships to other South American Predacious Marsupials	Elmer S. Riggs	
Pt. 2—A Commentary on Loureiro's "Flora Cochinchinensis"	E. D. Merrill	$5.00
Volume XXV—Report of the Pennsylvania Local Government Survey	H. F. Alderfer, Edward W. Carter, Philip B. Willauer, Bradford W. West, Blake E. Nicholson	4.00
Volume XXVI—Siwalik Mammals in the American Museum of Natural History	Edwin H. Colbert	5.00
Volume XXVII—Anatomy of the Rat	Eunice Chace Greene	5.00

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HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

VOL. 76 1936 No. 1

THE THORACIC AND ABDOMINAL VISCERA OF PRIMATES, WITH SPECIAL REFERENCE TO THE ORANG-UTAN

WILLIAM L. STRAUS, JR.

The orang-utan, being one of the anthropoid apes, long has greatly interested anatomists. Beginning with Peter Camper (1779), many investigators have studied the structure of this animal from various aspects. Thus a number of papers devoted to the anatomy of the orang-utan deal, in more or less detail, with the structure and topography of the thoracic and abdominal viscera, and considerable data on individual organs and organ systems are to be found in studies of more limited scope.

Yet, with few exceptions, these studies have been restricted to immature animals. For obvious reasons, fully adult orang-utans but rarely are available for dissection. Thus I welcomed the opportunity of studying the thoracic and abdominal viscera in a large, fully adult, male orang (J. H. Anat. no. 212). This animal, after but a few months in captivity, died following an apparently brief illness. It was embalmed with 10 per cent formalin within a few hours after death. Dr. D. B. Remsen, of the Department of Pathology and Bacteriology, The Johns Hopkins University, most kindly examined the viscera following their dissection. He has informed me that he encountered lesions characteristic

of tuberculosis. The organs that appear to have been most affected are the lungs, liver and spleen.

This huge male orang-utan (anterior trunk height = 49.8 cm.) constitutes the basis of the present study. Comparison will also be made with two other orangs, a juvenile male and a newborn female. The former (J. H. Anat. no. 37) lived for a number of years in the National Zoölogical Park, Washington, D. C. Upon death it was found to be extremely rachitic. Preservation was obtained by embalming with 10 per cent formalin. The anterior trunk height was 27.6 cm. The observations made upon the viscera of this particular animal unfortunately were somewhat limited and fragmentary, particularly with respect to visceral topography. The newborn orang (U. S. N. M. no. 153825) was procured for study through the kindness of Mr. Gerrit S. Miller, Jr., of the Division of Mammals, United States National Museum. Preservation was in 70 per cent alcohol. The anterior trunk height was 12.9 cm. I am indebted to Dr. Adolph H. Schultz for information regarding the trunk heights of these specimens.

I also am greatly indebted to Miss Angela Bartenbach for Figs. 2, 7, 11 and 13, to Mr. Melford D. Diedrick for Fig. 8, and to Mr. Leon Schlossberg for Figs. 3 and 14. These splendid drawings were procured through the kindness of Professor Max Brodel.

The present communication consists, first, of a description of the thoracic and abdominal viscera of the three orang-utans, which will be referred to in subsequent pages as "the adult," "the juvenile," and "the newborn." Comparisons are made with data in the literature relating to other examples of this animal.

Secondly, for purposes of orientation and comparison, considerable information regarding the conditions in other primates is included in parts of the discussion. These latter data have been obtained partly from the literature, and partly from my own investigations of some 30 various primates during the past several years. I am greatly indebted

to Mr. Gerrit S. Miller, Jr. for the opportunity to study several of these specimens.

A few words of explanation and caution are necessary with respect to accounts of visceral topography. Firmly anchored organs, such as the kidneys, duodenum and pancreas (in most animals), and even the heart, probably do not undergo significant topographical changes following death. But those structures that exhibit great mobility during life, particularly those portions of the gastro-intestinal tract as are intraperitoneal, may exhibit deceptive changes in position, especially in relation to the bony landmarks of the body wall. These may be partly dependent upon the position of the animal at the time of embalming. (It should be mentioned that the two older orangs were placed flat on their backs during embalming; the position of the newborn orang during fixation is unknown to me.) To obviate at least many of these post mortem distortions in topography, it would be necessary to employ methods similar to those used by Schreiber (1931, '32). Since this has not been possible in the material under consideration, I have considered only those exact topographic relations as seem not to be greatly distorted by artifacts. Yet even here the possibility of some post mortem distortion must always be kept in mind.

Furthermore, a great difficulty presents itself in a consideration of the lengths and weights of the various organs, in that these measurements, for obvious reasons, have not been obtained under uniform conditions. Thus some data in the literature (*e.g.* those of Kohlbrügge, 1900) relate to fresh material, other data to specimens preserved in a variety of ways. There likewise exists the possibility of post mortem changes of many kinds. All this practically excludes, at least in the material under consideration, any serious direct comparison of organ weights and lengths between *different* individuals. Nor can comparisons of lengths—such as those of the intestines—with body measurements that presumably change but little following death and preservation—such as trunk height, sitting height or stature—be other than ex-

tremely approximate. Yet in spite of these difficulties, certain information may be obtained by comparisons of lengths and weights within the same animals, by means of ratios. And these ratios probably can be compared, with at least some degree of certainty, among individual specimens. Yet a further complicating factor must be noted. Not infrequently, and especially in animals that have lived in captivity, various organs are found to be diseased. Care must be taken to exclude such material from consideration. This has been done in the specimens which I have studied.

The majority of my specimens were preserved in 10 per cent formalin. The *Tupaia lacernata*, the *Tarsius philippinensis*, the *Galago*, the two examples of *Nycticebus*, and the newborn orang-utan, however, were fixed in alcohol, while the viscera of the *Perodicticus potto* were preserved in Bouin's fluid. The human material was procured from the dissecting room. Measurements of stomach and intestines were made after their removal from the body. Care was taken to avoid stretching of the gut. For the later specimens this was best accomplished by measuring with a string. By this method the natural curves and coils of the gut could easily be followed.

THORACIC VISCERA

Heart

A. Orang-utan.—The heart (*cor*) is quite human in its general form, as can be seen from Fig. 2 (also cf. Ruge, 1893). Its internal structure has not been studied by me. The weight of this organ—including its great vessels—is 493 g. (formalin fixation) in the adult, 145 g. (formalin fixation) in the juvenile, and 12 g. (alcoholic fixation) in the newborn. The weight of the adult heart thus is 41 times that of the newborn; one cannot say just what allowance must be made for the differences in fixation.

The pericardium is firmly attached to the upper surface of the diaphragm. In the adult animal the visceral and parietal layers of the pericardium are connected by fibrous adhesions.

The newborn exhibits an interesting condition, in that the apex of the heart protrudes through a patent foramen pericardiacum. Hence the apex cordis is separated from the left lung by only a thin membrane representing the mesothelium of the left parietal pleura and pericardium (Fig. 3). This particular interesting and rare developmental anomaly has already been described in detail by Dr. C. F. De Garis (1934) in a separate communication. It is impossible to determine how far this anomalous condition has affected the relations of the heart to surrounding structures.

The relation of the heart to the anterior thoracic wall is not quite the same as that found in man. In the adult the base of the heart lies behind the sternum at the level of the 1st intercostal space, while the cardiac apex lies to the left at the level of the 5th costal cartilage. In the newborn the base is situated behind the sternum at the level of the 2d intercostal space, and the apex in the 4th intercostal space of the left side, above the upper border of the 5th costal cartilage. These probably are instances of individual variation, and not representative of a true ontogenetic change. The apex of the heart in a young male orang-utan examined by Ruge (1893, Fig. 12) lay behind the 5th costal cartilage.

FIG. 1. The aortic arch and its branches in the writer's 3 orang-utans. In both newborn (*N*) and juvenile (*J*) but two vessels—truncus communis and left subclavian artery—arise from the arch, while in the adult (*A*) a truncus communis is absent, so that the left common carotid artery also takes origin from the aorta. The truncus communis is relatively longer in newborn than in juvenile.

The angle between the long axis of the heart and that of the trunk as determined by the course of the inferior vena cava (cf. Ruge, 1893), was about 60° in the adult and approximately 55° in the newborn. Ruge (1893) found this angle to be 74° and 75° respectively in two orang-utans that he examined. The lack of agreement between our results possibly may be traced to slight differences in the technique employed.

The arrangement of the branches arising from the arch of the aorta is of interest, in that this is a detail which long has engaged the attention of comparative anatomists. The three orangs studied by me do not exhibit the same pattern. In both the newborn (Fig. 1, *N*) and the juvenile (Fig. 1, *J*) but two vessels arise from the arch: the truncus communis and the left subclavian artery. The former vessel divides into the left common carotid and the innominate arteries. Truncus communis is relatively longer in the newborn animal. The adult orang exhibits the usual human pattern (Figs. 1, *A* and 2). Thus three arteries arise from the arch: innominate, left common carotid and left subclavian. The vessels, however, are slightly more crowded than is usual in man. According to the data collected by Parsons (1902), but 1 out of 17 orang-utans exhibited the usual human arrangement of the branches of the aortic arch; the remaining 16 were of the type noted in my newborn and juvenile specimens. The condition in my adult animal therefore is of relatively rare occurrence in orang-utans.

In marked contrast to man, the orang exhibits a great disparity in caliber between the common carotid and the subclavian arteries, in favor of the latter vessel (Figs. 1 and 2). An interesting growth change is apparent here, for the disparity is most pronounced in the adult. In both juvenile and newborn the subclavians likewise are the larger vessels, but the discrepancy in size is not as striking as in the older specimen.

B. Other Primates.—The following data taken from Tanja (1891) and Ruge (1893) are illustrative of the phylogenetic changes in the relations of the heart to the anterior thoracic wall, whereby the apex of this organ undergoes a cranial migration. In Old World monkeys the apex of the heart usually lies at the level of the 6th intercostal space or behind the 6th rib; occasionally it may be situated as high as the 5th intercostal space or as low as the 7th rib. In anthropoid apes, the cardiac apex is situated at a higher level: in the siamang at the 4th space, in the gorilla behind the 5th rib (for

the orang, vide supra). Man thus is intermediate (5th space) between the catarrhine monkeys and the apes. Similarly, the long axis of the heart in lemurs and monkeys is directed essentially in a craniocaudal direction, and hence it forms a smaller angle with the long axis of the trunk (or inferior vena cava) than it does in the anthropoid apes and man (cf. Ruge, 1893). According to Woollard (1925), the angle between heart and inferior vena cava is larger in *Tarsius* than in lemurs.

The arrangement of the branches of the aortic arch in primates has been studied quantitatively by Keith (1895), Parsons (1902), and De Garis, Black and Riemenschneider (1933). In most mammals but two vessels arise from the arch: the truncus communis—to use the terminology of De Garis et al.—and the left subclavian artery (Fig. 1, *N.* and *J*). This is the condition characteristic of (1) lemurs, (2) some New World monkeys, *e.g. Ateles*, (3) Old World monkeys, (4) the gibbons, and (5) the orang-utan (vide supra). The prevailing human arrangement (Fig. 1, *A*) (3 vessels—innominate, left common carotid and left subclavian arteries—from the arch) is characteristic of (1) *Tarsius*, (2) most marmosets, (3) many cebid New World monkeys, *e.g. Cebus*, (4) the chimpanzee, (5) the gorilla, and (6) man (the so-called mammalian type is most frequent in the Negro; see De Garis et al.). From an ontogenetic point of view, the aortic arches of the orang-utan and most other primates are more specialized than that of man (for justification of this conclusion, see De Garis et al., p. 616).

The weight of the adult heart averages 10.6 times that of the newborn heart in the langur, *Semnopithecus* sive *Pygathrix* (Kohlbrügge, 1900), 12.7 times in Europeans (Vierordt, 1906), 15.4 times in Filipinos (De Jesus, De Leon et al., 1933). These values agree quite closely. If the similar figure of 41 for the orang-utan (vide supra) can be regarded as even approximately comparable, the difference in this great ape—in contrast to the monkey and man—is very striking indeed.

Thymus

A. Orang-utan.—The thymus in the newborn orang is a relatively large and well-developed structure (Fig. 3). It lies just behind the sternum in the broad anterior mediastinum, anterior to the upper part of the pericardium, and exhibits right and left lobes of about equal size. These extend upward into the cervical region, and laterally downward around the pericardium adjacent to the medial parietal pleura. No trace of this gland was encountered in the adult.

B. Other Primates.—The thymus of both man and chimpanzee (Sonntag, 1924 *b*) resembles that of the orang, in that it is composed of two lobes. In both the fetal gorilla and the fetal gibbon, however, three lobes—left, right and superior—can be recognized (Deniker, 1886). This trilobate condition likewise occurs in the fetal chacma baboon, *Papio porcarius* (Anthony & Villemin, 1923), and in the infant rhesus monkey, *Macaca mulatta* (Miller & Leonard, 1933). The thymus of *Tarsius*, which persists even in the adult animal, is a bilobate structure (Woollard, 1925).

Trachea

A. Orang-utan.—The trachea exhibits its usual relations, lying anterior to the esophagus throughout its course. The tracheal cartilages are incomplete posteriorly in both adult and newborn; the juvenile was not examined for this point. Anthony (1898), Narath (1901, Fig. 222), and Sonntag (1924 *a*) also have noted that the tracheal cartilages are incomplete in the orang-utan.

Bifurcation of the trachea occurs at about the level of the disc between the 3d and 4th thoracic vertebræ in the adult, and at the level of the 4th thoracic vertebra in the newborn. As in man, the right bronchus is more vertical than the left. In the orang-utan studied by Cunningham (1886), the tracheal bifurcation lay opposite the 3d thoracic vertebra, in that of Anthony (1898), however, at the level of the 6th thoracic vertebra.

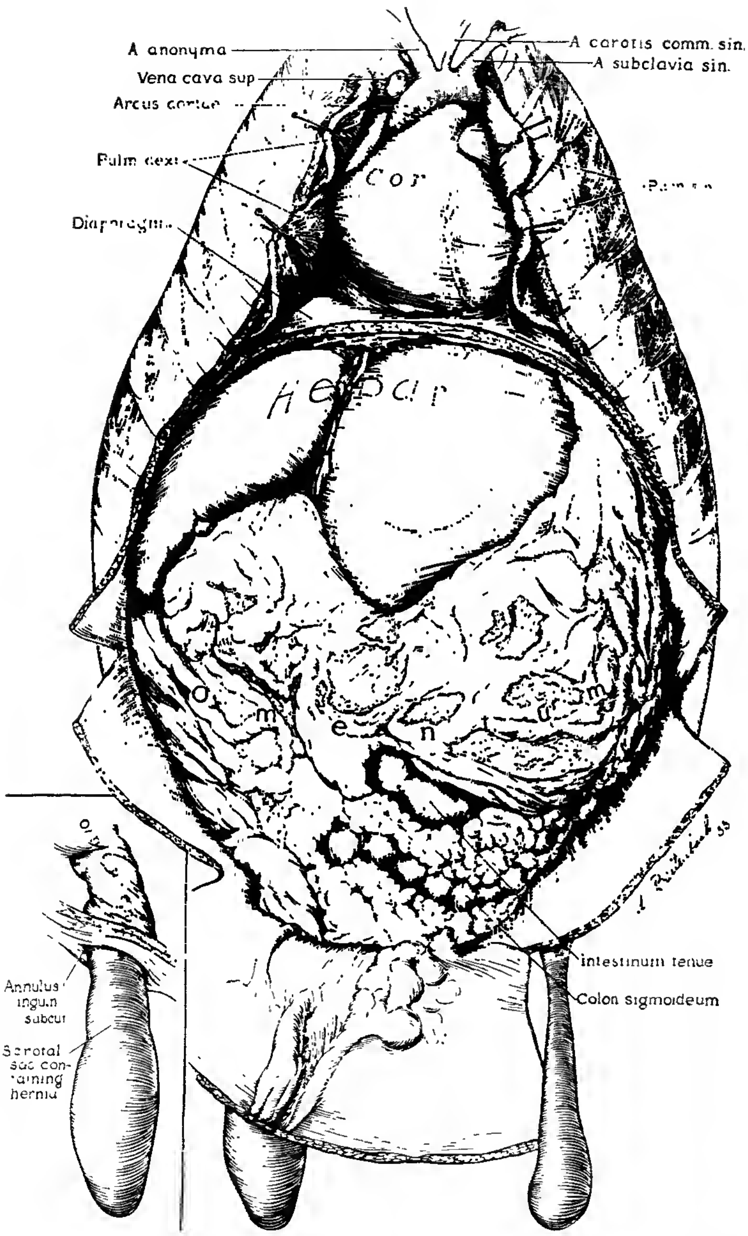

FIG. 2. Ventral view of thoracic and abdominal organs of adult male orang-utan (J. H. Anat. no. 212) in situ. The sternum has been removed and the abdominal wall cut and reflected. Some of the epiploic fat has been cut away so as to expose portions of the intestines. The position of the stomach is indicated by dotted lines. The insert shows details of the inguinal hernia.

B. Other Primates.—The tracheal cartilages may occur as complete rings in some genera of lemurs and apparently on occasion in *Tarsius* as well (Straus, 1931). In other primates, however, the cartilages exhibit a dorsal deficiency, at least in all specimens that have come to my attention.

According to Cunningham (1886), division of the trachea occurs opposite the 5th thoracic vertebra in the chimpanzee, opposite the 4th in adult man, and opposite the 3d in newborn man. In Sperino's (1897) chimpanzee the tracheal bifurcation was at the level of the disc between the 4th and 5th thoracic vertebræ. The postnatal descensus occurring in man is not found in the orang-utan, at least not in the scanty material at hand.

Lungs

A. Orang-utan.—The lungs (*pulmones*) of the three orangs are grossly non-lobate. A few vestigial fissures, however, are present. The left lung of the adult exhibits two small, short and relatively shallow fissures, one along the cardiac border, the other extending from the root to the base of the lung along the line of reflection of the pulmonary ligament; the right lung similarly presents a short but relatively deeper fissure along the cardiac border, but the one near the root is absent. Other very minute and superficial fissures were noted. The lungs of the juvenile also possess a few short and relatively shallow fissures; these are more pronounced in the right lung than in the left (Fig. 4). The lack of gross lobation is even more emphasized in the newborn; the lungs are practically devoid of fissuration, only one short and shallow cleft being noted on the lateral aspect of the right lung, but this is quite incomplete and fails to reach either margin of the organ. A definite cardiac notch is present in the left lung (Fig. 3).

In the right lung of the orang, the vestige of the mammalian lobus azygos, also termed lobus impar or lobus subpericardiacus, may perhaps be present. Hence, in the newborn orang, there is a slight projection of lung tissue in the region of the pulmonary ligament behind the inferior vena

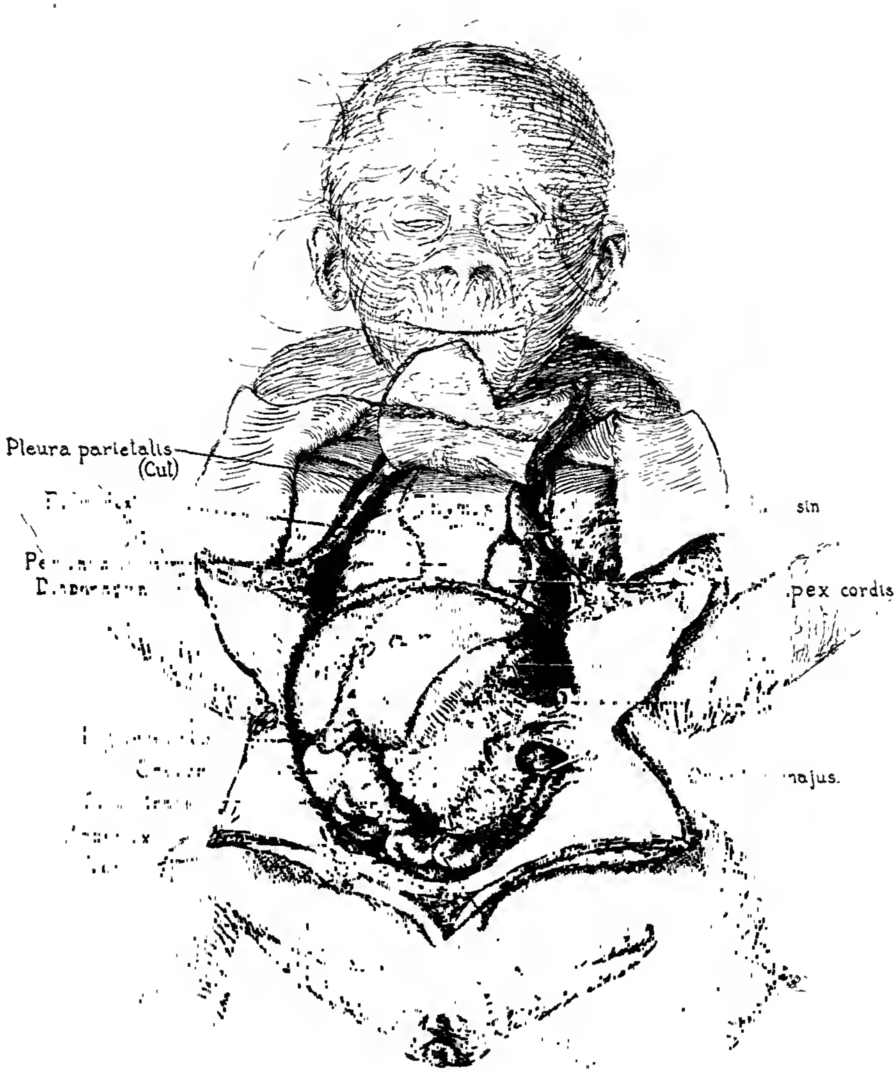

FIG. 3. Ventral view of newborn female orang-utan (U. S. N. M. no. 153825). The sternum and the abdominal wall have been cut and reflected so as to expose the thoracic and abdominal organs.

cava, this agreeing in position with the free lobus azygos of other primates. Yet there is a corresponding projection in the left lung that is even better developed.

The lungs of the orang-utan regularly are devoid of gross lobation. Such was the condition encountered by Huxley (1864), Chapman (1881), Hartmann (1886), Anthony (1898), Narath (1901, in 6 animals), Sonntag (1924 *a*), and by Broca and Chudzinski (both cited by Anthony). Incomplete fissures, however, sometimes were present. Such structures were encountered by Narath in 3 of the 12 lungs that he studied; in each instance the right lung was so affected. Yet gross lobation of the lungs apparently may occur. Thus while Jeffries (1826) merely stated that "the lungs were not so distinctly divided into lobes" as in man, Mayer (1856) noted 2 lobes in each lung, and Fick (1895) clearly suggested that there were 3 lobes, with an indication of a fourth, in the right lung of the orang that he studied. Wood-Jones (1929) stated that division into lobes is absent "in most examples."

The azygos lobe of the right lung in the orang apparently may be clearly indicated (Fick), or else it may occur in the condition described for my newborn orang-utan (Ruge, 1893; Narath). In some specimens even this vestige was not encountered (Aeby, Anthony).

Despite the absence of demonstrable lobes, the structures at the roots of the lungs are arranged as in man in all three specimens of orang-utan (Fig. 4). Thus there is an eparterial bronchus on the right side, but none on the left. Sonntag (1924 *a*) also noted, in a young female orang, that the structures entering and leaving the hilus of each lung were disposed as in man.

The lung weights of my orang-utans, which, however, are of very limited value, are as follows: Adult (formalin fixation)—left 607 g., right 475 g.; Juvenile (formalin fixation)—left 78 g., right 91 g.; Newborn—left 12 g., right 12 g. Even when roughly comparing these weights, the grossly pathological condition of the lungs of the adult animal must be kept in mind.

B. Other Primates.—The normal absence of gross pulmonary lobation in the orang-utan is an extreme specialization that is unparalleled among primates. In this character the orang resembles the sloths (Wislocki, 1928), the marsupial *Phascolarctos* and some cetaceans (Sonntag, 1924 *a*). Yet in the fetal three-toed sloth lobes are indicated (Wislocki). It would be of interest to determine if the usual arrangement found in the postnatal orang is the result of a similar onto-

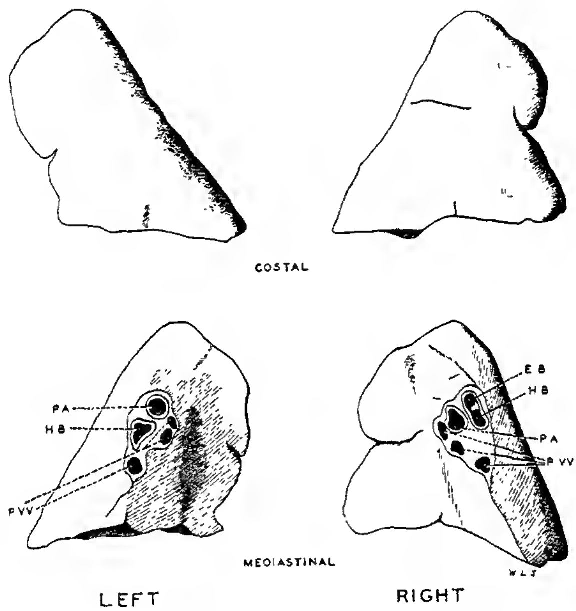

FIG. 4. Lungs of juvenile male orang-utan (J. H. Anat. no. 37). *P. A.* = pulmonary artery; *P. VV.* = pulmonary veins; *E. B.* = eparterial bronchus; *H. B.* = hyparterial bronchus.

genetic coalescence. Such a growth change is at least strongly suggested by the vestigial fissures encountered in my specimens.

The most primitive primate with respect to gross pulmonary lobation is *Tarsius*. The left lung possesses either 3 (Straus), 4 (Duckworth, Wood-Jones, Woollard, Straus) or 5 lobes (Leche), while the right lung has either 5 (Duckworth, Wood-Jones, Straus) or 6 lobes (Leche, Woollard, Straus),

one of which is an azygos. Passing to the lemurs, we find a numerical lobar reduction, the usual formula being L 3, R 4, although the left lung not infrequently is divided into but two portions. Essentially the same conditions exist in both groups of monkeys, except that in these primates there is a further tendency to reduce the number of lobes in the left lung to two. A still greater coalescence of lobes has occurred in the anthropoid apes and in man. In the gibbons the apparently constant formula is L 2, R 4 (Sonntag, Wood-Jones), while in both the chimpanzee and gorilla the azygos lobe has been lost in addition (various authors), yielding a normal formula of L 2, R 3, as in man. The culmination of the reductive process is found in the orang-utan.

Pleura

A. Orang-utan.—In all three animals the anterior reflection of the pleura on each side passes wide of the sternum, along the costal cartilages. In the adult, however, the two reflections converge markedly in a superior direction, and approach the sternal border; thus at the level of the 1st rib the reflections practically touch the margins of the sternum. The left pleural sac in general makes a closer sternal approach than does the right. Inferiorly, in the 5th intercostal space, the pleural reflection swings sharply lateralward, and on each side reaches the bony thorax at the level of the 6th rib.

Posteriorly, the pleura is reflected over the vertebral column at about the middle of the 12th thoracic vertebra in both adult and juvenile, the reflection being bilaterally symmetrical. In the newborn, however, the vertebral reflection on each side occurs at the level of the lower part of the 11th thoracic vertebra. These probably are instances of individual variations.

The pleural reflections of the orang-utan have been studied also by Tanja (1891) and by Ruge (1893, 1910). In Tanja's specimen the anterior pleural border on each side was reflected off the sternum, yet the space between the two margins was considerable. At the level of the 5th rib each reflection passed lateralward over the 5th costal cartilage to attain the

bony thorax over the 6th rib. Posteriorly the pleura was reflected off the middle of the 12th thoracic vertebra. Ruge found the pleura to be reflected anteriorly off the manubrium sterni on the right side, and from the costosternal junction on the left. Below this point, bilaterally, the line of reflection ran along the costal cartilages, reaching bone over the 6th rib. Posterior reflection was bilaterally off the middle of the 12th thoracic vertebra. In a second animal the pleura was reflected posteriorly at the level of the upper border of the 12th thoracic vertebra on each side.

B. Other Primates.—Both Tanja and Ruge also have carefully investigated the pleural sacs of many primates, and the reader is referred to their papers for details. The most interesting points refer to the ventral (sternal) and vertebral reflections. In the lemurs and Old World monkeys the ventral reflections, coincident with the narrow sternum, approach one another very closely. In the gibbon, chimpanzee and man the ventral reflections tend toward greater separation, the individual variability being considerable. The most extreme separation, to a degree that is unique among primates, occurs in gorillas and orang-utans. This tendency toward dissociation of the pleural sacs most probably is correlated with the broadening of the sternum and the shift of the cardiac axis in the apes and man. In the lemurs, the level of the vertebral reflection of the pleura may be as low as the 17th thoracolumbar vertebra (Tanja, Ruge), in tarsiers the 15th (Woollard). This reflection, despite a considerable individual variability, generally is at a considerably more cranial level in monkeys, gibbons and chimpanzees. The phylogenetic process of an upward pleural shift is even more marked in the gorilla and man, and is most extreme in the orang-utan.

Esophagus

A. Orang-utan.—This structure presents no noteworthy features. It pursues its usual course through the thorax posterior to the trachea, and pierces the diaphragm to continue into the stomach.

ABDOMINAL VISCERA

Stomach

A. Orang-utan.—The stomach (*gaster*) of the adult orang-utan—empty at the time of fixation—is more elongate than is usual in man, and its long axis is rather in a craniocaudal direction (Figs. 2 and 5, *I*). The organ is almost completely covered by the huge left lobe of the liver. The left portion of the stomach—*i.e.* that part lying to the left and above a line drawn longitudinally through the esophagus and continued through the stomach—seems relatively smaller than in man. A fundus is not well marked. Externally the stomach exhibits no constrictions, and internally a pyloric antrum is not sharply demarcated. The internal gastric ridges are very well marked and run in a longitudinal direction. Length (formalin fixation) along the lesser curvature from esophagus to duodenum is 16 cm., along the greater curvature 37 cm.

The stomach of the juvenile orang—also empty at the time of embalming—is more human in form, being less elongate than that of the adult. Yet here also the left portion is not large. There is a notch in the lesser curvature, producing an internal projection that clearly marks off the pyloric antrum. Length (formalin fixation) along the lesser curvature is 11 cm., along the greater curvature 27 cm.

The newborn orang possesses a stomach—likewise empty at death—that is long and curved (Fig. 5, *H*), somewhat suggesting that of an example of *Lemur variegatus* studied by me (Fig. 5, *D*). Although it is elongated, it does not closely resemble that of either juvenile or adult, in that it is much curved upon itself. Thus the esophageal and duodenal orifices tend to be approximated toward one another as in the particular specimen of *Lemur*. There is a curious cone-shaped projection of the fundus immediately adjacent to the esophagus, suggesting the condition in the human fetus (cf. Keith, 1933, Fig. 311); this may well be a transient ontogenetic feature. The pyloric antrum is not marked off by a

constriction or shelf. Internally, the wall is thrown into a honeycomb of ridges; these are pronounced in the first part of the stomach, but disappear as the pylorus is approached. Length (alcoholic fixation) along the lesser curvature is 5.5 cm., along the greater curvature 12 cm. The organ is not as extensively covered by the liver as in the adult (Fig. 3).

The orang stomach has been studied by a number of investigators. Some of the differences may perhaps be traced to the condition at the time of fixation. As in the writer's specimens, it usually is quite elongate (Huxley, Chapman 1881, Sonntag 1924 *a* and *b*), and its form may differ from that of the chimpanzee and gorilla, as well as from that of man (Chapman, Sonntag). Mayer found it to be rounder than that of the chimpanzee which he studied. Sonntag (1924 *a*) found no fundic projection, and the organ was oriented in a cranio-caudal direction, these conditions agreeing fairly well with those encountered in my adult. According to Wood-Jones, however, the fundus is well-marked. Jeffries noted that the cardiac orifice was "perhaps smaller," and the pylorus larger, than in man. As in the writer's juvenile animal, the pyloric antrum frequently is well-demarcated (Flower, Chapman 1881, Klaatsch, Fick, Anthony, Sonntag 1924 *a* and *b*, Sandifort cited by Sonntag 1924 *b*).

B. Other Primates.—Ephemeral variations in form notwithstanding, it appears that the stomach exhibits distinct differences among the primate groups. In the tarsiers and many lemurs (*Galago* sp., *Nycticebus* sp., *N. borneanus*, *Perodicticus potto*) the stomach is quite globular in form as in the tree-shrews, with the left portion, as defined above, extremely well-developed (Figs. 5, *A*, *B*, *C*, *E*). The esophageal and duodenal openings thus tend to lie comparatively close together (also cf. Flower, Milne-Edwards & Grandidier, Woollard, Wood-Jones). The fundus may be large. In *Lemur variegatus* (Fig. 5, *D*), however, the gastric form by no means is globular, and the stomach is bent back upon itself in a U-shaped manner; furthermore, the fundic projection is not particularly well-developed (also cf. Wood-Jones). In

other species of the genus *Lemur*, however, the stomach exhibits the usual lemurine form (Wood-Jones).

Among the monkeys of the New World, the stomach of the marmosets (Fig. 5, *F*) resembles that of most lemurs in the possession of a very marked left portion (Beattie, Wood-Jones, Straus). Of the cebids, I have noted that *Saimiri sciureus* exhibits a well-developed left gastric portion, but this may be less pronounced than in some lemurs (Fig. 5, *G*). The stomach of *Ateles* resembles that of man, but seems to be

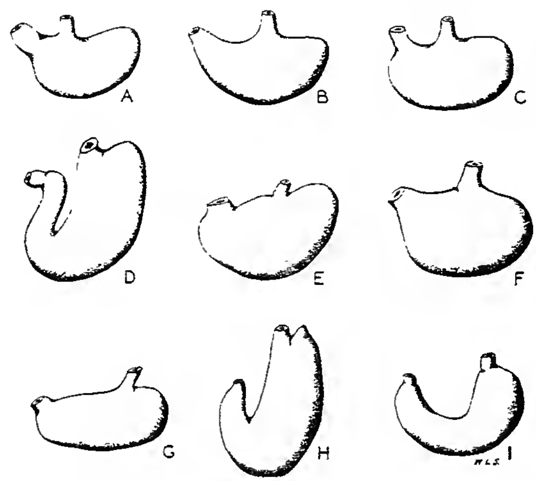

FIG. 5. Form of the stomach in (*A*) *Galago* sp. (U. S. N. M. no. 221436); (*B*) *Perodicticus potto* (J. H Anat. no. 283); (*C*) *Nycticebus* sp. (U. S. N. M. no. 142235); (*D*) *Lemur variegatus* (J. H. Anat. no. 11); (*E*) *Tarsius philippinensis* (U. S. N. M. no. 218238); (*F*) *Callithrix jacchus* (J. H. Anat. no. 75); (*G*) *Saimiri sciureus* (J. H. Anat. no. 8); (*H*) Orang-utan, newborn female (U. S. N. M. no. 153825); (*I*) Orang-utan, adult male (J. H. Anat. no. 212).

more elongate and slender, while in *Cebus* it is more globular (Flower).

In the Old World monkeys of the subfamily Lasiopyginæ the stomach is essentially human in form. On the other hand, in the subfamily Colobinæ, including the genera *Pygathrix*, *Nasalis* and *Colobus*, the stomach is enormously sacculated, the degree of complexity suggesting the similar organ of ungulates. For descriptions of the colobine stomach the reader is referred to Owen, Flower, Berenberg-Gossler,

Duckworth, Pernkopf. Such type of gastric specialization is restricted to this subfamily.

The stomachs of the anthropoid apes rather closely resemble that of man. That of the gibbon is strikingly human in its general form (Flower, Straus), though it is rather more globular (Flower). According to Wood-Jones, the fundus is not marked. The stomach of the chimpanzee likewise is essentially human in form (Flower, Straus), though less so than that of the gibbon (Flower). The stomach of the gorilla resembles that of man (Bolau, Bischoff), but it is less elongated than those of orang and chimpanzee (Bischoff), and more globular than that of man (Duckworth, Sonntag, 1924 *b*).

A well-marked pyloric antrum existed in a chimpanzee which I examined, while both Flower and Sonntag noted a sharp demarcation of the pylorus in this ape. In a specimen of *Hylobates leucogenys*, I found the pylorus clearly set off from the body of the stomach, but not by a ridge as in the chimpanzee. According to Leche (1898–99), the pyloric antrum is better marked in the anthropoid apes than in man. It also is strongly defined in *Ateles* (Flower, Leche), *Mycetes* sive *Alouatta* (Leche) and *Hapale* sive *Callithrix jacchus* (Beattie).

Duodenum

A. Orang-utan.—The duodenum of the adult orang-utan begins from the pylorus at about the upper border of the 11th thoracic vertebra and descends almost to the level of the iliac crest, *i.e.* to the 2d lumbar vertebra. Thus its cranial and caudal limits are about two vertebræ higher than in man. Except for the immediate first part, the duodenum is retroperitoneal in position. It consists of a short superior portion, a quite long descending portion, and a terminal horizontal portion that is somewhat longer than the superior (Fig. 6, *H*). An ascending portion clearly is absent, and in this the animal contrasts markedly with adult man. The superior mesenteric vessels pass across the horizontal portion as in man. Duodenal length (formalin fixation) is 14 cm. A musculus sus-

pensorius duodeni (of Treitz) was not found. Upon opening the duodenum, definite valvulæ conniventes (plicæ circulares Kerkringi) can be seen for its entire length. These do not form complete circular folds, but rather a honeycomb arrangement with the circular ridges predominating. They are least prominent about the openings of the pancreatic and bile ducts. Internally, also, along the left aspect of the descending portion of the duodenum—about 8 cm. beyond the pyloro-duodenal junction—can be seen a prominent papilla duodeni major, upon which the common bile duct and the pancreatic duct (of Wirsung) empty by separate openings. A true ampulla of Vater thus is lacking. About 2 cm. nearer the pylorus, and situated more ventrally, is a definite though smaller and less prominent papilla duodeni minor bearing the opening of the accessory pancreatic duct (of Santorini).

The duodenum of the juvenile is similar to that of the adult in that a fourth or ascending portion is absent (Fig. 6, *G*). It is retroperitoneal in position. The relation to the superior mesenteric artery and vein are as in the adult animal. Valvulæ conniventes are absent. The pancreatic and common bile ducts open, apparently separately, upon a low papilla major, but no papilla minor for an accessory pancreatic duct was noted.

The newborn duodenum differs in form from that of adult and juvenile, for, in addition to superior, descending and horizontal parts, it possesses a fourth or ascending portion (Fig. 6, *F*). Hence it is annular and resembles the duodenum of man. It is retroperitoneal in location. Beginning at about the lower level of the 11th thoracic vertebra, it descends almost to the iliac crest, which latter is situated at about the level of the disc between the 2d and 3d lumbar vertebræ. Duodenal length (alcoholic fixation) is 5.5 cm. The musculus suspensorius duodeni is absent. Valvulæ conniventes are quite apparent. These are circular folds in the upper part of the tube; distally they produce a rather incomplete honeycomb effect. The papilla major is prominent. It is located in the descending portion, about 3.5 cm. beyond

the pylorus. The common bile and pancreatic ducts open upon it by separate orifices. There is no papilla minor.

Sonntag (1924 *a*) found the duodenum of his orang-utan to be retroperitoneal—except of course for the first part—as in the writer's animals, but Anthony (1898) encountered a duodenal mesentery, in that the duodenum was contained in the transverse mesocolon. In Cunningham's (1886) animal the duodenum was in relation with the 1st and 2d lumbar vertebræ. Klaatsch (1892) stated that in his orang the duodenojejunal flexure was situated about three vertebræ above the promontorium. Sonntag found that the duo-

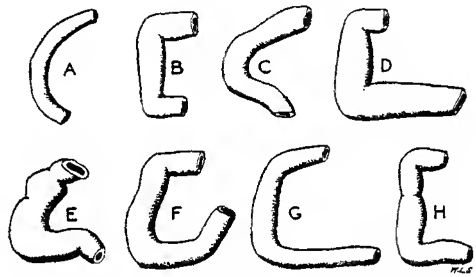

Fig. 6. Form of the duodenum in (*A*) *Lemur variegatus* (J. H. Anat. no. 11); (*B*) *Saimiri sciureus* (J. H. Anat. no. 388); (*C*) *Papio papio* (J. H. P. A. L. no. 47); (*D*) *Hylobates leucogenys* (J. H. P. A. L. no. 73); (*E*) Chimpanzee (J. H. Anat. no. 162); (*F*) Orang-utan, newborn female (U. S. N. M. no. 153825); (*G*) Orang-utan, juvenile male (J. H. Anat. no. 37); (*H*) Orang-utan, adult male (J. H. Anat. no. 212). Note the absence of a true fourth or ascending portion in all except *F*.

denum described its usual loop, but that the first part was ascending rather than horizontal. Quite different were the conditions encountered by Anthony. Here the duodenum began slightly to the left of the midline, and formed a single loop, concave superiorly, so that the duodenojejunal flexure was situated on the right side of the body. Mitchell (1905) stated that there was "no distinct duodenum" in the orang that he studied. Apparently, therefore, both duodenal form and structure are more variable in the orang-utan than they are in man. As in my animals, a musculus suspensorius duodeni was absent from those of Anthony and Sonntag. Hence a deficiency of this supporting structure seems to be

characteristic of the orang. Duodenal valvulæ conniventes have been noted by some investigators, but not by others (see Jacobshagen, 1930). These folds, when present, vary greatly in degree of definition as well as in form. Regarding the papilla duodeni major, Sonntag failed to locate one in his animal, in which the bile duct merely emptied by a foramen. Anthony noted an ampulla of Vater, but no accessory papilla, since in his animal there was but one pancreatic duct.

The relative length of the duodenum (when the jejuno-ileum = 1) is 0.037 in my adult male orang-utan and 0.053 in my newborn female.

B. Other Primates.—In tarsiers, lemurs and some New World monkeys there is a definite primitive mesoduodenum, derived from the dorsal mesentery (Beattie, Flower, Klaatsch, Van Loghem, Treves, Woollard, Straus). This structure, however, has become relatively shortened in the New World monkeys (Van Loghem, Treves), and may even be absent (Van Loghem, Straus), as in a specimen of *Saimiri sciureus* examined by me. The duodenum regularly lacks a dorsal mesentery in all other primates (Klaatsch, Van Loghem, Treves, Straus), but it may occur in some specimens of Old World monkeys (Duckworth, Straus), as I found in a *Papio papio*, in which a partial mesoduodenum was present.

The exact form of the duodenum varies greatly in primates, although it is singularly constant in man, exceptions to the text-book descriptions being exceedingly rare (Treves). The fourth or ascending portion is practically constant in man (Treves). In other primates, however, this part seems not infrequently to be absent, this presumably being the result of an incomplete rotation of the duodenum. For example, in addition to the two older orangs, I have definitely noted the absence of a fourth or ascending portion in the chimpanzee, gibbon (*Hylobates leucogenys*), *Papio papio*, *Erythrocebus patas*, *Saimiri sciureus* and *Lemur variegatus*. In both the chimpanzee (Fig. 6, *E*) and the gibbon (Fig. 6, *D*) the superior portion scarcely existed, but the descending and transverse portions were both long; in the *Saimiri* (Fig. 6, *B*) there was a

rather short superior, a long descending and a very short inferior portion; in the *Papio* (Fig. 6, *C*) the duodenum formed an incomplete loop; while in the *Lemur* (Fig. 6, *A*), a duodenum did not exist in the human sense, the first part of the small intestine merely describing a long arc around the pancreas. A true pars ascendens, however, sometimes may be very prominent, as in my newborn orang and a second specimen of *Erythrocebus patas*, in the chimpanzee (Sonntag, 1924 *b*, Schreiber, 1932) and in the common marmoset (Beattie).

As in the orang, the musculus suspensorius duodeni is absent in the chimpanzee (Sonntag, 1924 *b*).

The occurrence of duodenal valvulæ conniventes in primates apparently is an extremely variable feature, at least in some forms. Jacobshagen (1930) has considered these structures in great detail. Presumably they are in large part of an ephemeral character. According to my own experience, they usually are absent in preserved specimens of primates, and when they occur, as in examples of *Hylobates leucogenys* and *Lemur variegatus*, they are of a network or honeycomb type.

A papilla duodeni major is not confined to the so-called higher primates. This structure is well-defined, for example, in a specimen of *Saimiri sciureus* at hand. In this animal it exhibits a single opening internally, and no accessory papilla is present.

The relative length of the duodenum (jejuno-ileum = 1) in a few of my specimens follows (for the orang, vide supra): *Saimiri sciureus*, ad. ♀, 0.055; *Erythrocebus patas*, juv. ♀, 0.065; *E. patas*, infant ♂, 0.079; *Macaca mulatta*, ad. ♀, 0.032; Chimpanzee, juv. ♂, 0.046; Negro, ad. ♀, 0.054. No definite generic or group differences can be noted. This possibly is due to the insufficient number of specimens. Nevertheless, judging from these samples, it may tentatively be stated that the duodenal length in the Anthropoidea customarily is about 5 per cent of the length of the jejunoileum, but that a rather considerable degree of variability exists.

Jejuno-ileum

A. Orang-utan.—At the duodenojejunal flexure the duodenum bends sharply and passes into the jejunum. The second (jejunum) and third (ileum) parts of the small intestine are entirely intraperitoneal, being supported by the mesentery proper. They form a complex series of coils framed by the large intestine (Fig. 7).

Valvulæ conniventes are present in all three animals. In the adult they occur throughout the length of the jejunum and ileum, appearing as true, complete plicæ circulares, with some longitudinal and oblique folds, so that in certain regions there is a network or honeycomb effect. The valvulæ, however, are very faint or else completely absent where the intestine is greatly dilated, an occurrence lending support to the view of Jacobshagen (1930) that they are of an ephemeral nature. In the juvenile, the valvulæ, which are absent from the duodenum, appear in the first part of the jejunum as somewhat circular rings, then disappear, and finally are again indicated for a short space, once more disappearing previous to the ileocecal junction. They never approach those of the adult in distinctness. The valvulæ of the newborn extend throughout the small intestine. Over the upper jejunum they are of a honeycomb nature, but for the remainder of the small intestine they are quite apparent as numerous, rather prominent circular folds.

Length of the jejuno-ileum is 372.5 cm. in the adult (formalin fixation), 102 cm. in the newborn (alcoholic fixation).

From the reports of several workers, the occurrence of valvulæ conniventes in the jejuno-ileum of the orang is a variable character, as it is in the duodenum. It might be mentioned that Mitchell (1905) found that the minor loops of the jejuno-ileum in his orang were arranged in proximal and distal sets.

B. Other Primates.—The jejuno-ileum (Mitchell's so-called Meckel's tract) always possesses a mesentery in primates, and in this respect remains the most primitive portion

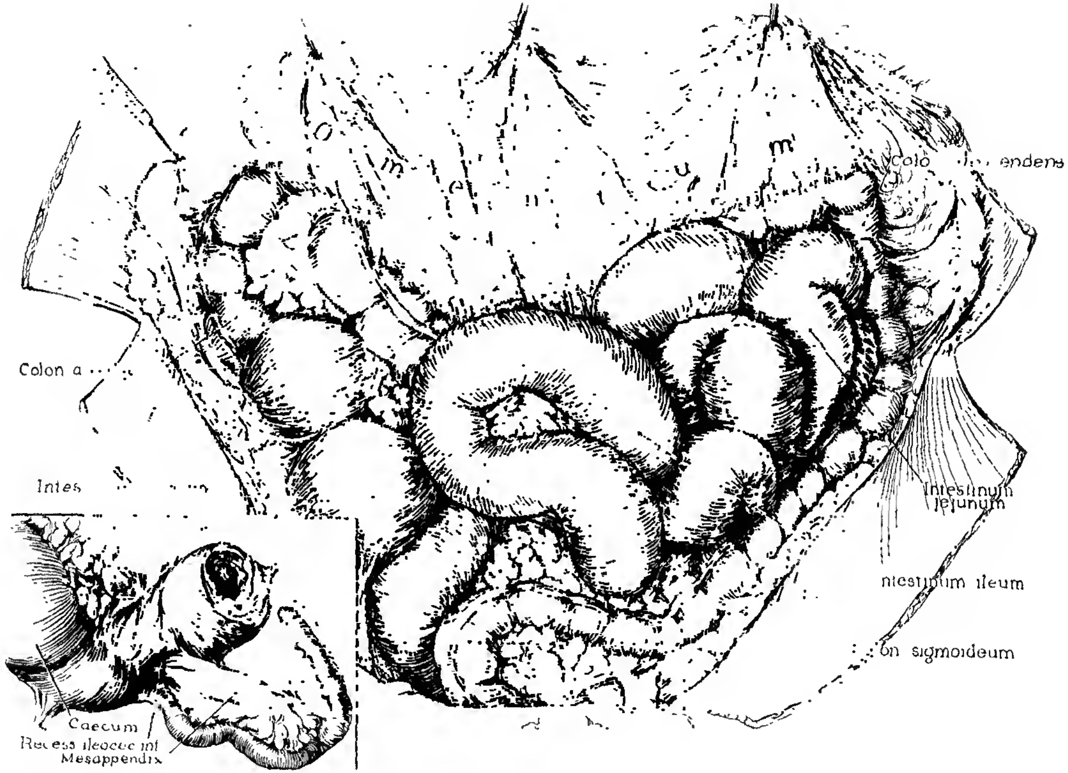

Fig. 7. Ventral view of abdominal organs of adult male *orang-utan* (J. H. Anat. no. 212) in situ. The abdominal wall has been cut and reflected, the greater omentum raised, and much of the peri-intestinal fat removed. The insert shows the ileocæcal region.

of the bowel. The occurrence of valvulæ conniventes, as in the orang, is variable (cf. Jacobshagen, 1930).

Cæcum

A. Orang-utan. The cæcum of the adult orang-utan (Fig. 7) lies in the right iliac fossa, the ileocæcal junction being near the level of the iliac crest, the latter rising almost to the disc between the 2d and 3d lumbar vertebræ. In form the cæcum is of Treves' (1885) type 3 (see Fig. 9), although closely approaching his type 4, in that the vermiform appendix arises just below the ileocæcal junction (Figs. 7, 8, 10). The shortness of the colic teniæ divides the cæcum into two distinct pouches, a large one to the right, and a small triangular one to the left. The right pouch is covered by peritoneum, but is so closely approximated to the posterior body wall that no real mesocæcum exists. The left pouch exhibits a narrow posterior area that is retroperitoneal, and from its triangular apex a strong peritoneal band—the cæcal fold—extends downward to fuse with the peritoneum of the right iliac fossa. Three well-marked teniae converge to the base of the appendix vermiformis. The latter arises from the left aspect of the cæcum, close to the ileocæcal junction. It passes to the left behind the ileum and the mesentery proper and then down into the right iliac fossa. It is a well-developed, stout structure, twisted slightly upon itself, and without any tapering. No true appendicular valve can be found internally, the appendix first appearing as a sudden constriction of the cæcum. There is a stout appendicular peritoneal fold—the mesappendix—engorged with fat, derived from the mesentery of the terminal ileum, and extending practically to the tip of the appendix (Fig. 7). Length of cæcum is 12.5 cm., length of appendix 18 cm. (formalin fixation). The ileocæcal junction forms a true valve—the valvula coli—greatly resembling that of man (Fig. 8). The ileal termination, which is directed obliquely downward into the cæcum, presents a valve formed by two thick lips. These

lips fuse laterally to form a thick frenulum, which thus produces a greatly narrowed cæcocolic aperture.

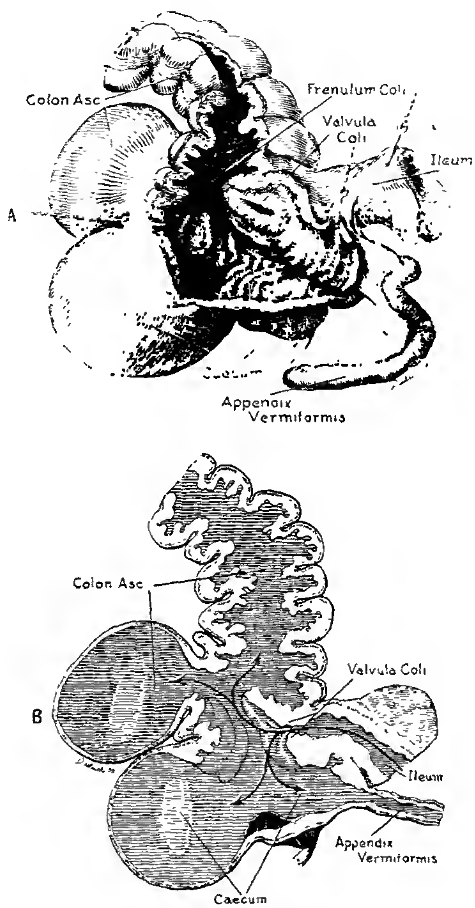

FIG. 8. Cæcum and first portion of ascending colon of adult male orang-utan (J. H. Anat. no. 212), viewed ventrally. *A*, cæcum and colon cut open to show internal details of ileocæcal junction. *B*, semi-diagrammatic view of the interior, after mid-frontal section, to show further details.

The cæcum of the juvenile orang-utan differs somewhat from that of the adult (Fig. 10). It clearly is of Treves' type 3, for the vermiform appendix arises a couple of centimeters below the ileocæcal junction. Peritoneal investment is complete, so that the cæcum is movable. There is no

division into two pouches. The three teniæ converge to the root of the appendix. The latter is a stout structure that is twisted to form one spiral. No appendicular valve is present. There is a well-marked mesappendix. Length of cæcum is 6.5 cm., length of appendix 15.5 cm. (formalin fixation). The ileocæcal valve closely resembles that of the adult, although the two lips are not as closely approximated. It is directed somewhat toward the cæcum, so that cæcum and colon again are separated medially by a high, thick wall. Laterally, the cæcal wall protrudes inward as a thick fold (apparently formed by a thickening of the muscular coat), which helps form a cæcocolic partition or valve. Thus, as in the adult, the cæcocolic orifice is very narrow; this presumably is not a post mortem artifact.

The newborn cæcum resembles that of the juvenile, in that it likewise is of Treves' type 3 (Fig. 10). In situ, it gives the appearance of being incompletely descended, for it is situated just caudal to the liver (Fig. 3). Yet it lies slightly below the level of the iliac crest. There is a rather short cæcal supporting fold of peritoneum, so that this pouch is somewhat movable. In form the cæcum is a blunt, rather conical sac, without subdivision into pouches. The three teniæ disappear over the upper portion of the cæcum, far from the root of the vermiform appendix, and hence do not appear to converge toward the latter point. The appendix is relatively long, and much twisted in a spiral manner. There is no definite appendicular valve, but the wall of the cæcum internally is thickened and thrown into ridges just where the appendix begins. A strong mesappendix is present. Length of cæcum is 2 cm., length of appendix 8.5 cm. (alcoholic fixation). The ileocæcal valve points directly downward into the cæcum. It does not present two well-marked lips as in the juvenile and the adult specimens, but appears as a prominent crescentic fold, that fades out laterally, as a frenulum, toward the cæcocolic junction. The latter orifice is much constricted as in the older animals. The absence of well-defined valvular lips possibly is the result of post mortem lack of contraction in this part of the bowel.

In the present series of animals, the appendix vermiformis becomes relatively much shorter with growth (in relation to cæcum). Compared to length of cæcum, its length is as 4.25 to 1 in the newborn, 2.38 to 1 in the juvenile, and only 1.44 to 1 in the adult. This ratio is 2.77 and 2.12, respectively, in Von Eggeling's two orangs, and 2.70 in Sonntag's (1924 *a*) specimen. The average value for the 5 animals (excluding my newborn) is 2.28.

The form of the cæcum in the orang-utan has been studied by many investigators (Anthony, Chapman, Von Eggeling, Fick, Flower, Huntington, Van Loghem, Lorin-Epstein, Mitchell, Reider, Sonntag, etc.). In most animals

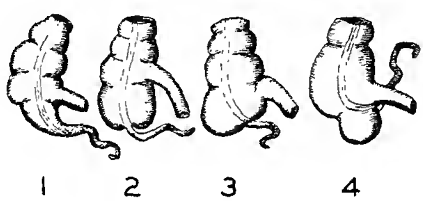

Fig. 9. The four types of appendiferous cæca (after Treves, 1885). In 1, the so-called "fetal" type, the apex cæci is a cone which tapers into the vermiform appendix; in 2, the true apex cæci (and appendix) is not the summit of a cone, but lies between two equally bulging sacculations; in 3, the portion of the caput cæci lying to the right of the anterior tenia has grown out of proportion to the part lying to the left, so that the true apex cæci (and appendix) approaches the ileocæcal junction; in 4, the portion of the cæcum lying to the right of the anterior tenia is greatly hypertrophied, that to the left atrophied, so that the true apex cæci has disappeared and the appendix seems to arise almost from the ileocæcal junction.

the form greatly resembles that of the human fetus, in that the cæcum is funnel-shaped, with gradual transition to the vermiform appendix (see Lorin-Epstein, 1932). Such specimens are of Treves' type 1 or even in some instances apparently of his type 2. A few orangs in addition to my own, however, possess cæca that are of an adult human type (cf. Anthony, Chapman, Jacobshagen 1923, Van Loghem, Sonntag 1924 *a*), and hence fall into Treves' 3d or possibly even his 4th category, as do all three examples that I studied. Cæcal diverticula have been found by Lorin-Epstein. The appendix may be coiled or spiralled (Flower, Hartmann, Huntington, Sonntag 1924 *b*), or it may describe one wide arc (Lorin-

Epstein, his Figs. 10 and 11). In some adult animals the length of the appendix may equal (Flower) or even exceed (Chudzinski, Huntington) that of my adult male. Anthony found no appendicular valve in his animal, this being in agreement with the condition in my specimens; Lorin-Epstein saw some sort of valve in one orang, but not in another. As in my newborn, the teniæ coli cannot always be traced to the root of the appendix (*e.g.*, see Lorin-Epstein, his Fig. 10). Sonntag (1924 *a*) noted that his orang-utan lacked an ileocæcal valve in the human sense, while this structure as described and figured for the orang by Lorin-Epstein appears to differ from the conditions encountered by me. Chapman (1881), however, found this valve to be as in man. Both Von Eggeling and Lorin-Epstein noted that the cæcocolic aperture was sharply indicated or much constricted in the orangs that they studied; this condition is in agreement with the arrangements encountered in my three animals, and would thus appear to be at least of frequent occurrence in the orang-utan.

The relative length of the cæcum may be procured by comparison with colon (= 1) or with small intestine (= 1). Compared to the colon, the relative cæcal lengths (not including the vermiform appendix) in my three orangs are: Adult ♂, 0.09; Juvenile ♂, 0.07; Newborn ♀, 0.04. When length of small intestine is substituted for that of colon, the values are 0.03, 0.02 and 0.01, respectively. Including the specimens studied by Von Eggeling and Sonntag, the cæcum/colon ratio for 5 orangs (excluding my newborn) averages over 0.05, with extremes of 0.04 (Von Eggeling, Sonntag) and 0.09 (Straus). The cæcum/s. i. ratio for 4 animals (Von Eggeling, Straus) averages somewhat more than 0.01, with extremes of 0.01 (Von Eggeling) and 0.03 (Straus).

B. Other Primates.—The cæcum of primates has received careful attention from many investigators (*e.g.* Von Eggeling, Huntington, Jacobshagen, Van Loghem, Lorin-Epstein, Mitchell, Reider, Treves). The exact form and relative size varies considerably (vide infra). In most genera it is a rather

simple blind sac, although in some lemurs (as *Lemur* and *Galago*) it may be considerably coiled or spiralled (cf. Von Eggeling, Van Loghem, Reider, and my Fig. 10, *D* and *E*).

The relative cæcal lengths of a tree-shrew (*Tupaia*) and some primates studied by me are herewith given; the first figure in each instance represents cæcal length relative to colon, the second figure relative to small intestine: *Tupaia lacernata*, ad. ♀, 0.43 and 0.02; *Tarsius philippinensis*, ad. ♂, 0.77 and 0.14; *T. saltator*, ad. ♀, 1.28 and 0.18; *Lemur variegatus*, ad. ♂, 0.66 and 0.38; *L. variegatus*, ad. ♀, 0.68 and 0.37; *Galago* sp., ♂, 0.37 and 0.27; *Nycticebus borneanus*, ad. ♀, 0.10 and 0.08; *N.* sp., ad. ♂, 0.19 and 0.17; *Perodicticus potto*, ad. ♀, 0.11 and 0.12; *Callithrix jacchus*, ♂, 0.25 and 0.18; *Saimiri sciureus*, ♂, 0.63 and 0.05; *Ateles geoffroyi*, ad. ♂, 0.37 and 0.07; *Erythrocebus patas*, juv. ♀, 0.06 and 0.02; *E. patas*, infant ♂, 0.07 and 0.02; *Macaca mulatta*, ad. ♀, 0.07 and 0.03; *M. mulatta*, juv. ♂, 0.13 and 0.04; *Cercocebus aethiops*, juv. ♀, 0.06 and 0.02; *C. lunulatus*, juv. ♀, 0.06 and 0.02; *Papio papio*, juv. ♂, 0.04 and 0.02; *P. papio*, juv. ♀, 0.08 and 0.02; *Pygathrix entellus*, ad. ♂, 0.05 and 0.02; *Hylobates leuciscus*, ad. ♂, 0.10 and 0.04; Chimpanzee, juv. ♂, 0.07 and 0.02; Negro, ad. ♀, 0.06 and 0.02; White, ad. ♂, 0.08 and 0.01; White, fetus (ca. 7 mos.), ♀, 0.05 and 0.01.

These figures may be taken as representative, for they agree closely with those calculated from the extensive data of Von Eggeling, Jacobshagen (1930), Kohlbrügge, etc.

In the tree-shrews the cæcum is relatively rather long when compared with the colon, but extremely short when expressed in terms of small intestine (also cf. Le Gros Clark, 1926). This merely serves to emphasize the brevity of the colon in these animals (vide infra). The shortness of the cæcum relative to the small bowel may well indicate a secondary reduction of the former. Indeed, the cæcum has been reported as being absent in one species of *Tupaia* (see Mitchell, 1915, and Le Gros Clark, 1934).

In *Tarsius* the cæcum is relatively much longer than in either *Tupaia* or *Ptilocercus*, and in some instances may sur-

pass the colon in length. Yet the variability in this genus is considerable (various authors). But the cæcum is not very long in relation to the small intestine, this being an indication of the shortness of the large bowel in the tarsiers (vide infra).

Among the Lemuroidea, the cæcum frequently is comparatively long. The generic differences, however, are great. In some forms the cæcum has kept pace with the colon, which it may approach in length, as in *Indris* (Flower, Milne Edwards & Grandidier) and in some species of *Lemur*, particularly *L. variegatus* (cf. Jacobshagen 1930, and Von Eggeling). In other genera—such as *Galago*, *Avahis*, *Propithecus*, and some examples of *Lemur*—the cæcum is of moderate length when compared with either colon or small intestine, while in *Daubentonia*, *Perodicticus* and in at least some examples of *Nycticebus* it is relatively short.

Turning to the New World monkeys, the cæcum is not long in the marmosets of the genus *Callithrix*, while in *Leontocebus* it is slightly longer in relation to the colon (0.30), but shorter in comparison to the small intestine (0.09) (see Von Eggeling). These differences will be understood in the light of what will later be said concerning the relative colon lengths of these two genera of the Callitrichidæ. In the Cebidæ (*Ateles*, *Alouatta*, *Cebus*, *Saimiri*) the cæcum is moderately long—or even very long in *Saimiri*—in relation to colon, but uniformly quite short in relation to small intestine. If the conditions in *Tarsius* be accepted as the more primitive, then the cæcum of the Cebidæ has undergone a comparative linear reduction.

At any rate, the cæcum is most abbreviated in the catarrhines (Old World monkeys, anthropoid apes, man). In this group it is only occasionally that it attains as much as 10 per cent of the length of the colon. Apparently it is relatively slightly longer in *Macaca* than in other genera of Old World monkeys. That a relatively short cæcum is not caused solely by the formation of a vermiform appendix is quite apparent from a comparison of both types of relative cæcal length in man, apes and Old World monkeys. The

general agreement is striking, yet the monkeys possess no appendix.

For purposes of comparison, some detailed information herewith is given for the anthropoid apes. For gibbons, Von Eggeling's figures yield relative cæcal lengths of 0.05 (to colon) and 0.01 (to small intestine) in a *Hylobates agilis*, while the corresponding figures for my *H. leuciscus* are 0.10 and 0.04; in Deniker's gibbon fetus these ratios are 0.08 and 0.03, respectively. The data for the orang-utan already have been given. In the chimpanzee, the cæcum/colon ratios for 8 animals (Ehlers, Von Eggeling, Gratiolet & Alix, Jacobshagen, Sonntag, Straus) averages 0.05, with extremes of 0.02 (Gratiolet & Alix) and 0.10 (Ehlers). The average cæcum/s. i. ratio of these chimpanzees is 0.01, with limits of less than 0.01 (Gratiolet & Alix) and 0.02 (Ehlers, Sonntag, Straus). Six gorillas (Bischoff, Bolau, Jacobshagen, Van Loghem) yield an average cæcum/colon ratio of 0.10, with a range of variation extending from 0.07 (Bischoff) to 0.16 (Van Loghem). The cæcum/s. i. ratio for 5 gorillas (Bischoff, Bolau, Jacobshagen) averages 0.02, with extremes of 0.01 (Bolau) and 0.04 (Bolau, Jacobshagen). The relative cæcal lengths in Deniker's gorilla fetus are 0.07 and 0.02. As far as the present material is concerned, no clear-cut growth change in relative length of cæcum can be noted for either man, orang, gorilla or gibbon, nor does any occur in the langur, according to Kohlbrügge's data.

It may be concluded that the cæcum in Anthropoidea has undergone a comparative shortening, the greatest reduction occurring in the Catarrhinæ. The general tendency in the Lemuroidea is toward a relative lengthening, this presumably in association with a similar trend in the colon. These changes possibly are correlated with habits of digestion. If this be true, however, the significance is by no means clear.

A true appendix vermiformis occurs only in man and the four anthropoid apes. In certain histological features, however, such as in the relatively smaller amount of lymphoid tissue and in the character of the mucosa, the appendix of the

apes is less differentiated than that of man (Lorin-Epstein). These features are similar to those of the human fetal appendix (Lorin-Epstein). Thus apparently the anthropoid ape appendix has not evolved to the same degree as has that of man. In this connection some mention must be made of the very curious and interesting fact that at least some examples of the lorisine lemur *Nycticebus* (and *Loris*) exhibit a terminal cæcal appendage (Fig. 10, *F*) that can only be regarded as grossly homologous to the vermiform appendix of man and the apes (also cf. Von Eggeling, Huntington, Van Loghem). Histologically, however, the homology is lacking. In an alcoholic specimen of *Nycticebus* sp. at hand, despite the extremely poor state of preservation, histological preparations reveal that the morphology of the appendix is quite dissimilar to that of man, the general structure resembling that of the large intestine proper (on this point also see Von Eggeling). One nevertheless can readily regard the cæcal appendage of the slow loris as representing an early stage in the evolution of a true vermiform appendix. The lorises herein are paralleling a phylogenetic process occurring among the catarrhine primates, but the same stage of specialization has not been reached. Curiously enough, the potto, *Perodicticus*, which is closely related to *Nycticebus* and *Loris*, exhibits not the slightest indication of a cæcal appendage (Fig. 10, *G*); Reider, however, found that this structure can be present in the potto. It should likewise be mentioned that the caput cæci of some monkeys, which sometimes is regarded as a kind of appendix, is by no means homologous to that structure (on this point cf. Todd, 1931, and Reider). Apparently the macroscopic differentiation of the terminal cæcum to form a vermiform appendix precedes its microscopic differentiation in phylogeny. Thus the lorises, the anthropoid apes and man represent three morphological—but not genetic—stages in the evolution of the cæcal appendage. Reider did not regard the cæcal appendage of the lorises as a true vermiform appendix, but merely as "a contraction phenomenon in the cæcum." It is difficult to understand, however, why such a

phenomenon should be so very frequent in these genera, and not in other lemurs. The position sometimes adopted, that the term "appendix" should be reserved for those cæcal appendages that are specialized lymphoid organs, appears to me as an unjustifiable anthropocentric point of view.

The four-fold classification of human cæca proposed by Treves (1885) is based essentially upon the position of the vermiform appendix (Fig. 9). It therefore is applicable only to those cæca in which an appendix has been differentiated. In *Nycticebus*, as might be expected, the cæcum is of Treves' type 1—which presumably represents the primitive condition for appendiferous cæca, and which is the type commonly found in the human fetus. Treves stated that type 2—which apparently represents the next stage of differentiation—seems to be the form of cæcum most commonly occurring in the anthropoid apes. According to the data that have been collected by Jacobshagen (1923), the cæca of postnatal gibbons, orangs and chimpanzees usually are of types 1 and 2, the more advanced types (3 and 4) being of rather infrequent occurrence, especially in the first-named animals. The cæca of these three apes thus usually resemble those of prenatal man rather than those of adult man. This is quite in agreement with the histological characters of the anthropoid ape appendix as described by Von Eggeling and Lorin-Epstein. In the postnatal gorilla, however, the type 1 cæcum apparently does not occur (Jacobshagen); thus the cæcal characters of this animal are more nearly human than are those of the other apes. In the fetal gorilla of Deniker, however, as might be expected, the cæcum clearly was of type 1. The type 3 cæcum is present, according to the studies of Treves, in the great majority of postnatal men. Types 3 and 4 apparently are of late ontogenetic development, but they may be found, at least occasionally, during fetal life. Thus Treves saw a cæcum of type 4 in a full-term human fetus, while I found one of type 3 in a White female fetus of about 7 months (240 mm. CR. length).

The relative length of the appendix (cæcum proper = 1) in some primates studied by me, follows: *Nycticebus borneanus*, ad. ♀, 0.80; *N.* sp., ad. ♂, 0.69; Chimpanzee, juv. ♂, 2.10; Negro, ad. ♀, 1.18; White, ad. ♂, 1.17; White, fetus (ca. 7 mos.), ♀, 2.50.

Von Eggeling listed measurements for a specimen of *Nycticebus coucang* in which the appendix/cæcum ratio figures 0.66, and for an example of *Loris tardigradus* in which the same proportion is 0.96. These data, together with my own, suffice to demonstrate that in the Lorisinæ the cæcal appendage, which properly should be regarded as a rudimentary appendix, normally does not attain the length of the cæcum proper.

Among the gibbons, Von Eggeling's measurements of a *Hylobates agilis* yield an a./c. ratio of 1.85, my own for a *H. leuciscus* a ratio of 1.71, whereas in the siamang, *Hylobates* (= *Symphalangus*) *syndactylus*, studied by Van Loghem the appendix was shorter than the cæcum, the ratio being only 0.60. Possibly a species or generic difference exists. The ratio in Deniker's gibbon fetus is 1.41.

In the orang-utan, as noted previously, the average relative appendix length is 2.28, which is considerably greater than that of the Hylobatidæ.

Ratios calculated from 7 chimpanzees in the literature are: Von Eggeling, 3.34, 2.22 and 3.00; Ehlers, 0.93; Gratiolet & Alix, 3.07; Jacobshagen (1930), 1.94; Sonntag (1923), 1.53. Adding my juvenile male, the average is 2.26, practically identical with that of the orang.

For the gorilla, ratios for 6 animals follow: Bischoff (1880), 1.20; Bolau, 1.05, 1.11 and 1.00; Jacobshagen (1930), 0.62; Van Loghem, 1.00. The average is 0.99. The appendix therefore is relatively much shorter than in the other two great apes. The difference depends on or is accentuated by the fact that the cæcum, as I have pointed out above, seems to be relatively longer in the gorilla than in the other apes and man. In Deniker's gorilla fetus the relative appendix length is 1.06.

In man, as given previously, I found the average relative appendix length to be 1.17.

In conclusion, the appendix usually is shorter than the cæcum proper in the Lorisinæ and probably also in the siamang, about the same length in the gorilla, slightly longer in man, considerably longer in the gibbon, and over twice as long in both the chimpanzee and the orang-utan. When the available specimens are arranged in the order of approximate increasing age—as determined roughly by the total intestinal lengths—it is quite apparent that the vermiform appendix becomes relatively shorter (to cæcum) with advancing growth in both orang-utan and man. But in neither chimpanzee nor gorilla is such a process evident. Deniker, however, stated that in the gorilla the appendix, when compared with stature, seems to increase in length with advancing age, this being directly opposed to the growth change occurring in man. I have no means of assessing this statement, but in the orang-utan at least, the appendix, when compared to anterior trunk height, definitely shortens with growth. In my small human series, however, no change occurs in this proportion.

The morphology of the ileocæcal region is not of a uniform character among the primates. The immediate ileocæcal junction has been discussed by Mitchell, and more recently and more fully by Lorin-Epstein. My own observations do not seem to differ greatly from those of the latter author. In *Tarsius saltator* I find that the ileocæcal junction is quite simple, and no valvular arrangement is present, nor does the ileum project into the large bowel. This condition is quite similar to that found in such a basically primitive mammal as the tree-shrew *Tupaia lacernata.* In the latter animal, however, a rudimentary valve appears to be present in that the constricted neck of the cæcum exhibits a number of short longitudinal ridges. A simple junction also is apparent in some lemurs (as *Nycticebus*), the ileum projecting directly into the large intestine. In other lemurs (*Galago*, *Lemur variegatus*) the terminal ileum may form a definite papilla with constricted aperture that extends into the large bowel.

This papilla may project upward into the colon (*L. variegatus*). In a second specimen of *Lemur variegatus* no papilla is present, and the terminal projection of the small intestine is very slight, but the final ileal circular muscle is strongly developed. Among the New World forms, the common marmoset (*Callithrix jacchus*) possesses a papilla-like valve that extends up into the colon as in the *Lemur*, while in a squirrel monkey (*Saimiri sciureus*) no papilla is formed, but the termination of the ileum lies in a pocket of the colon and is sharply directed upward. In a recently studied example of the squirrel monkey the ileum does not project into the large bowel, and no valve is formed, the morphology of this region resembling that of *Tarsius*. All of the Old World monkeys examined for this point (*Papio papio*, *Cercocebus lunulatus*, *C. aethiops*, *Erythrocebus patas*, *Macaca mulatta*) are quite similar. In these animals the ileum projects markedly into the large bowel, and no papilla is formed. The terminal ileal opening is comparatively quite large and a definite valvular arrangement is not suggested. In a chimpanzee the end of the ileum projects into the large intestine as a papilla, this being in marked contrast to the orangs, which possess a true ileocæcal valve in the human sense.

Le Gros Clark (1934) recently has pointed out an interesting phylogenetic change in position of cæcum and ileocæcal junction (see Fig. 10). In certain primitive mammals, such as the tree-shrews, the cæcum points upward. In the tarsiers, it has rotated somewhat to the right and downward. This process is completed in the Anthropoidea (monkeys, apes, man). The rotation also affects the disposition of the colon, as will be pointed out later. It has long been known that a similar rotation occurs during the ontogeny of man and probably of monkeys and apes as well; hence in a sense the conditions in the adult tree-shrews and tarsiers might be regarded as the result of a developmental arrest.

Internal constriction of the proximal large intestine to form a sort of cæcocolic valve—as noted in the orang (Fig. 8)—also was encountered by me in a specimen of the tree-shrew

(*Tupaia lacernata*). In this animal the narrowing of the proximal colic aperture was produced by thickened longitudinal ridges, which might, however, conceivably be of transitory character. Yet the morphology of this region strongly suggests that they may have acted functionally as a sort of valve. According to Le Gros Clark (1934), a cæcocolic valve occurs in *Tarsius* and in New World monkeys, but not in Old World monkeys, anthropoid apes and man. Keith (1933), however, stated that a cæcocolic sphincter commonly is present in man.

Colon

A. Orang-utan.—The colon of the orang exhibits the same divisions as in man: Ascending, transverse, descending and sigmoid. In the adult orang-utan (Figs. 7 and 10, V), the ascending colon passes upward from the cæcocolic junction to the liver, to lie in contact with the posterior surface of the right hepatic lobe. It then makes a sharp bend to the left (hepatic flexure) to become the transverse colon. At its beginning, just above the cæcocolic orifice, the ascending colon exhibits a marked anterolateral outpouching or diverticulum, which communicates with the colon proper by a narrow aperture. A second colic pouch is somewhat indicated in the region of the hepatic flexure. The transverse colon does not pass directly across to the left side of the abdomen, but first turns rather sharply downward and to the left. Just to the right of the midline of the body it bends once more, to extend upward and to the left—though less abruptly—to the region of the spleen. Thus there is a distinct sagging or loop in the transverse colon. From the splenic flexure the descending colon passes inferiorly to the level of the iliac crest, then to the right but still downward in the true pelvis, where the sigmoid colon begins some few centimeters to the left of the midline. The sigmoid colon is truly sigmoidal in form. It passes somewhat to the right of the midline, curving back upon itself to reach the left of the midline, and then making another loop it goes to the right, finally bending downward into the rectum. Its loops are not as closely packed

together as they customarily are in man. The better part of the ascending colon is retroperitoneal, but a mesocolon appears just below the hepatic flexure. The entire transverse colon exhibits the usual mesocolon. Below the splenic flexure the descending colon lies retroperitoneally for a space, but then exhibits a mesocolon for the rest of its course. The entire sigmoid colon is supported by a well-developed mesocolon. The rectum is retroperitoneal in position.

The longitudinal musculature of the colon forms three prominent bands, the teniæ coli (tenia libera, t. omentalis, t. mesocolica), which first appear over the cæcum. They extend for the length of the colon, finally spreading out to fuse over the rectum. The relative shortness of the teniæ produces three rows of distinct sacculations, the haustra coli. The pericolic fat is relatively enormous in amount, forming huge appendices epiploicæ that completely hide the colon from anterior view. Internally, ridges suggesting the valvulæ conniventes of the small intestine occur throughout the length of the colon, but here they are in the form of short irregular folds. Length of colon (formalin fixation) is 138 cm.

The four parts of the colon also are clearly recognizable in the juvenile orang (Fig. 10, *M*). The ascending portion, however, is relatively shorter than in the adult. As in the latter animal, the immediate beginning of the colon forms a lateral diverticulum, bounded below by the lateral partition separating cæcum and colon, and above by a similar thickening of the lateral colic wall that protrudes into the lumen. The transverse colon, instead of making a single large downward bend as in the adult, forms two such lesser loops, one directly in the midline, the other near the splenic flexure. The sigmoid colon does not deserve its name, for it forms a single exaggerated bend in the vicinity of the cæcum. The entire colon possesses a mesocolon. Three distinct teniæ, producing marked haustra, are present. The appendices epiploicæ are rather large. Some internal ridging is evident. These ridges are of both a longitudinal and a honeycomb variety. Length of colon (formalin fixation) is 90 cm.

The ascending colon of the newborn orang-utan (Figs. 3 and 10, *L*) is extremely short. It exhibits no proximal diverticulum. The transverse colon is long and bent into two loops, the one nearer the splenic flexure being somewhat the more extensive. The descending colon is considerably longer than the ascending. The sigmoid colon is quite long and forms loops that are closely packed together. It is not truly sigmoidal in shape, however. The ascending colon has a rather short mesocolon, whereas those of the transverse and sigmoid portions are quite long. The descending colon is entirely retroperitoneal. There are three well-marked teniæ coli, with the accompanying haustra. Appendices epiploicæ are numerous. Internally, the colon exhibits many ridges, most of them longitudinal; true circular folds are absent. Length of colon (alcoholic fixation) is 49 cm.

The colon of the orang-utan may not invariably exhibit clear division into ascending, transverse, descending and sigmoid portions. Thus Mitchell noted in his animal that the hind-gut formed one large loop corresponding to the ascending, transverse and descending colons of man (this is a primitive sort of arrangement, and is possibly the result of a developmental arrest in this specimen), and that the sigmoid flexure was represented by a considerable portion of the large bowel that exhibited a number of minor loops. Flower, Sandifort (cited by Flower) and Reider all found that the sigmoid flexure was exaggerated, as in my adult specimen. Flower likewise mentioned that the colon was proportionately larger and longer, and hence more convoluted, than in man. Wood-Jones noted that the descending portion was highly tortuous. According to Reider, the general form of the colon in the orang is very similar to that in man. In Sonntag's (1924 *a*) animal both ascending and descending colons were short and had no mesocolons; the peritoneal attachment of the "iliac colon" was longer than that of the transverse. Klaatsch stated that the transverse colon of his orang formed a proximally open arch; both ascending and descending colons were retroperitoneal, but he pointed out that the relations

were probably complicated by the occurrence of peritonitis. Anthony encountered a mesocolon for the lower part of the ascending colon as well as one for the descending colon. Both Sonntag and Anthony noted many large epiploic appendices in their animals. Ridging of the colic mucosa was absent from Anthony's specimen, but Sonntag saw a few long folds.

The ratio between the large and the small intestines is of considerable interest. If the length of the entire small intestine be taken as 1, the relative lengths of the colon in individual orang-utans are as follows: Von Eggeling, 0.36 (no. I) and 0.26 (no. II); Straus, 0.35 (adult), 0.28 (juvenile) and 0.45 (newborn). Despite the occurrence of some fair degree of variability, it may be concluded that the average proportion between small intestine and colon in the orang-utan (excluding my newborn specimen) is about 1 to 0.31. This ratio is much the same as in the other anthropoid apes and man, as will be seen later.

B. Other Primates (Fig. 10).—Undoubtedly *Tarsius* possesses the most primitive type of colon of all primates (see also Van Loghem, Le Gros Clark 1934, Reider). The tarsioid form of colon could easily have been derived from the very simple condition found in certain of the insectivores (the tree-shrews, *Ptilocercus* and *Tupaia*), as Le Gros Clark has so convincingly demonstrated. In these animals the colon is a simple and usually quite straight organ, and the ileum and colon are of practically the same caliber (Fig. 10, *A*). The dextrocaudal rotation of the cæcum (mentioned above), as Le Gros Clark pointed out, produces a bending of the colic tube in the tarsiers (Fig. 10, *B* and *C*). The rotation seems to be variable in these animals, so that in some specimens a more or less distinct transverse colon may be recognized (*Tarsius philippinensis*) (Fig. 10, *C*), but a true ascending colon has not been evolved. The further development of the colon in the two groups of monkeys, in the anthropoid apes, and in man would seem to have been the result of a continuation of dextrocaudal cæcal rotation or migration. Hence in these animals two cranial colic flexures appear, and the colon is

more or less distinctly divided into ascending, transverse and descending portions (Fig. 10, *H–N*).

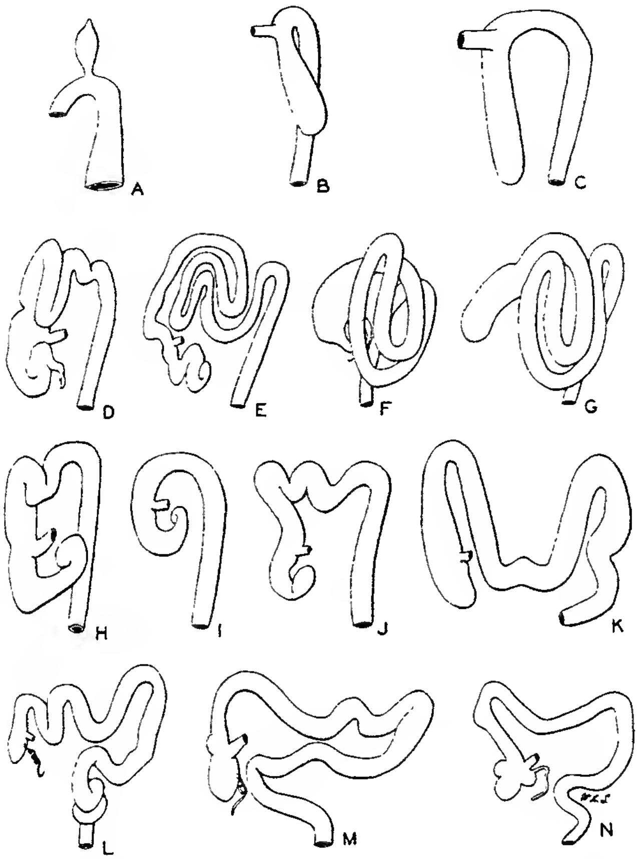

FIG. 10. The large intestine in (*A*) tree-shrew (*Tupaia lacernata*) (U. S. N. M. no. 123989); (*B*) *Tarsius saltator* (J. H. Anat. no. 169); (*C*) *Tarsius philippinensis* (U. S. N. M. no. 218238); (*D*) *Lemur variegatus* (J. H. Anat. no. 11); (*E*) *Galago* sp. (U. S. N. M. no. 221436); (*F*) *Nycticebus* sp. (U. S. N. M. no. 142235); (*G*) *Perodicticus potto* (J. H. Anat. no. 283); (*H*) *Callithrix jacchus* (J. H. Anat. no. 75); (*I*) *Saimiri sciureus* (J. H. Anat. no. 8); (*J*) *Ateles geoffroyi* (J. H. Anat. no. 150); (*K*) *Macaca mulatta* (Carnegie Col. no. F); (*L*) Orang-utan, newborn female (U. S. N. M. no. 153825); (*M*) Orang-utan, juvenile male (J. H. Anat. no. 37); (*N*) Orang-utan, adult male (J. H. Anat. no. 212).

The development of a sigmoid or omega portion of the colon in its terminal part is of relatively late phylogenetic occurrence. This structure is absent in the tree-shrews,

tarsiers, lemurs and platyrrhine monkeys (Fig. 10, *A–J*). Nor does it appear to occur regularly in the catarrhine monkeys, but Van Loghem, Reider and myself all have noted its presence in some animals. It is extremely variable in form. Thus while it was completely lacking in a fully adult male *Pygathrix entellus* examined by me, it was more complex than the corresponding section of the large bowel of man and anthropoids in one adult female *Macaca mulatta* (also see Leche, 1898–99, and Reider). A sigmoid colon is constantly present and well-developed in the three great anthropoid apes and man, although its exact conformation is subject to a considerable degree of variability (as in my three orangs; see Fig. 10, *L–N*). In my specimen of *Hylobates leucogenys* it exhibited a more typical human form than in any of the orangs. Yet the sigmoid flexure may be rudimentary or absent in some gibbons (see Flower, Van Loghem). Thus my example of *Hylobates leuciscus* exhibited only a very simple flexure of the terminal colon, without a definite sigmoid or omega loop being formed. Treves stated that it is not typically sigmoidal in man, but more like a capital Omega. He also indicated that it is more conspicuous in the human fetus than in the adult.

The well-known complex colon of the Lemuroidea is a unique and extreme specialization, not found in other primates. There is no real evidence to indicate, as Treves and Klaatsch evidently believed, that such a type of colon represents a primitive primate condition from which the simpler types found in the Anthropoidea have been derived. A relatively simple "lemurine colic loop"—or "ansa coli," as Le Gros Clark calls it—occurs in the true lemurs (*Lemur*) (Fig. 10, *D*), is more complicated in the lorises (*Loris*, *Nycticebus*, *Perodicticus*) (Fig. 10, *F* and *G*), and reaches its extreme in the sifaka (*Propithecus*), in which (see Van Loghem, Reider) it becomes a veritable labyrinth, involving both the anal and oral feet of the upper colon. The work of Van Loghem (1904) is very instructive in this connection. He found that in *Microcebus*—which is generally regarded as one of the most

primitive of the lemurs—the colon is exceedingly simple. No trace of a lemurine loop is present, and the general form (his Fig. 7) approximates that of *Tarsius*. The chief difference resides in a lengthening of the upper colon in *Microcebus* (Reider). Increasing colic complexity occurs in the more specialized lemurine types, such as the Lorisinæ and Indrisinæ. This in itself seems clearly indicative of a specialization occurring *within* the Lemuroidea, a circumstance of which Van Loghem clearly was cognizant (his Fig. 17). It furthermore is significant that Van Loghem found no lemurine colic loop in a 9-cm. fetus of the slender loris, *Stenops gracilis* (= *Loris tardigradus*), whereas the adult of this species possessed a typical lemurine loop. Similarly, notwithstanding the labyrinthine complexity of the colon in adult *Propithecus*, a 10-cm. fetus of this animal studied by Van Loghem showed only a rather simple lemurine type of loop; Jacobshagen (1930) encountered similar conditions in a *Propithecus* fetus of 18.3 cm. Without wishing to lay too much stress upon the ontogenetic findings, these facts nevertheless are extremely suggestive of the conclusion that the complex lemurine colon represents a specialized rather than a primitive primate condition. In this general conclusion the writer is in agreement with the recent views of Le Gros Clark (1934).

Both Klaatsch and Treves were greatly impressed by the fact that primates other than lemurs may show loops of various sorts in the transverse colon. The former investigator noted a rudimentary sort of lemurine loop in the transverse colon of a 6-cm. fetus of a marmoset, *Hapale* (= *Callithrix*) *albicollis*, that was absent in the adult of this species. As Le Gros Clark (1934) has stated, there is no reason for regarding this as representing a primitive condition. Treves found that the transverse colon of man was liable to a considerable variability in length, position and arrangement. It could not be followed in a straight line from the hepatic to the splenic flexure, and certain remarkable bends were sometimes formed. Such bends were always downward and usually abrupt and angular, forming a V or U. He concluded that

such bends or loops might at times be the result of distention, but that some represented congenital malformation. The congenital bends he was inclined to interpret as atavistic, and as a return to the colic form of such animals as the lemur. I have encountered such loops, not only in the three orang-utans (vide supra), but also in other Anthropoidea (chimpanzee, *Macaca mulatta*, *Ateles geoffroyi*, *Callithrix jacchus*) as well (Fig. 10). Loops in the transverse colon, at times reminiscent of those of lemurs, also have been found in Old World monkeys by Schreiber (1932). It is extremely unlikely, however, that any phylogenetic significance should be attached to these loops or bends. This portion of the large intestine (transverse colon) is the freest region of the large bowel in all primates, and consequently extremely subject to postural and physiological adaptations. It might be suspected that this very freedom offered a sort of passive stimulus for the development of a complex colic loop in this region in the Lemuroidea, in which for some unknown reason the apparently inherent tendency toward looping has been carried to an extreme. Certainly it would be quite hazardous to regard the transverse colic bends of man, orang, chimpanzee and monkeys as atavistic variations.

Reider, from an extensive investigation of the large intestine in primates, has concluded that the lemurine loop or coil is always the product of the proximal colon, *i.e.* that portion previous to the splenic flexure. With this conclusion my own more fragmentary observations agree. It appears that it is normally the more distal portion of the proximal colon—that portion which forms the transverse colon of man, apes and monkeys—that is especially involved. This also seems to have been the view of Flower (1872). The distal colon, *i.e.* that portion beyond the splenic flexure, more particularly the first part, is the most conservative region of the large bowel during primate phylogeny; it is only its second or terminal part that is involved in the modification that produces the sigmoid colon.

Thus, as has been seen from the preceding discussion, the

specializations of form within the primate colon relate solely to two portions, namely, the last portion of the proximal colon, prior to the splenic flexure, and the last portion of the distal colon, previous to the rectum.

Teniæ coli are not present in *Tupaia lacernata*, in which the longitudinal muscle forms a continuous and even layer over the entire large intestine. They are also absent from *Tarsius* (Jacobshagen 1930, Reider, Straus). The arrangement of the longitudinal cæco-colic musculature varies enormously in the Lemuroidea: (1) Teniæ may be absent, as in *Daubentonia* (Jacobshagen), *Lemur* (Jacobshagen), *Galago* (Flower, Van Loghem, Jacobshagen, Straus), *Microcebus* (Van Loghem, Reider), *Loris* (Van Loghem, Jacobshagen), *Nycticebus* (Van Loghem, Reider), and *Perodicticus* (Van Loghem); (2) one tenia may be present, as in *Nycticebus* and *Perodicticus* (Reider); (3) two teniæ may occur, as in *Lemur* and *Nycticebus* (Straus); (4) there may be three teniæ, as in *Lemur* and *Nycticebus* (Jacobshagen); or (5) even four teniæ may be present, as in *Lemur* and *Propithecus* (Van Loghem). The definition of these bands usually is weaker than in the Anthropoidea, and frequently they disappear in the distal colon. In the cæcum they may either be absent, or even more apparent and more numerous than in the large bowel proper. The New World monkeys may possess three teniæ coli (Van Loghem, Reider), but these are not always well-defined; there may be but one discernible, as in *Alouatta* (Flower), or they may be completely lacking, as in *Saimiri* (Van Loghem, Straus) and *Cebus* (Reider). Three marked teniæ are regularly present in Old World monkeys, apes and man (Flower, Van Loghem, Reider, Straus). The gibbons seem normally to have four teniæ developed in the cæcum, one of these disappearing in the colon (Van Loghem). In *Hylobates leuciscus*, however, I found only three teniæ in both cæcum and ascending colon.

Epiploic appendices appear regularly to be absent from the large intestine of tree-shrews, tarsiers, lemurs and both groups of monkeys, but are present and normally well-de-

veloped in the anthropoid apes and man (also cf. Reider). They seem to be neither as numerous nor as conspicuous in the Hylobatidæ as they are in the other anthropoid apes and man: for in a fully adult male *Hylobates leuciscus* I noted only a few rather small and irregularly distributed appendices.

The relative colon length (small intestine = 1) exhibits profound differences in the several primate groups. Its values in a specimen of tree-shrew (*Tupaia*) and in individual specimens of primates (the orangs have already been discussed) whose intestinal lengths I have measured, follow: *Tupaia lacernata*, ad. ♀, 0.05; *Tarsius philippinensis*, ad. ♂, 0.18; *T. saltator*, ad. ♀, 0.14; *Lemur variegatus*, ad. ♂, 0.58; *L. variegatus*, ad. ♀, 0.55; *Galago* sp., ♂, 0.73; *Nycticebus borneanus*, ad. ♀, 0.75; *N.* sp., ad. ♂, 0.88; *Perodicticus potto*, ad. ♀, 1.12; *Callithrix jacchus*, ♂, 0.71; *Saimiri sciureus*, ♂, 0.09; *Ateles geoffroyi*, ad. ♂, 0.19; *Erythrocebus patas*, juv. ♀, 0.39; *E. patas*, infant ♂, 0.40; *Macaca mulatta*, ad. ♀, 0.48; *M. mulatta*, juv. ♂, 0.31; *Cercocebus aethiops*, juv. ♀, 0.40; *C. lunulatus*, juv. ♀, 0.37; *Papio papio*, juv. ♂, 0.51; *P. papio*, juv. ♀, 0.27; *Pygathrix entellus*, ad. ♂, 0.36; *Hylobates leuciscus*, ad. ♂, 0.42; Chimpanzee, juv. ♂, 0.27; Negro, ad. ♀, 0.30; White, ad. ♂, 0.22; White, fetus (ca. 7 mos.), ♀, 0.24.

The above values, in virtually all instances, agree very well with relative colon lengths calculated from data found in the literature, of which there should especially be mentioned the extensive lists of Von Eggeling (1920) and Jacobshagen (1930).

In the tree-shrews, in which the digestive tract is of a very generalized mammalian type, the colon is extremely short, its length relative to the small intestine being but 0.05 in *Tupaia lacernata*. But in the pen-tailed tree-shrew, *Ptilocercus lowii*, the colon/small intestine ratio is somewhat greater, being 0.20 according to the measurements of Le Gros Clark (1926). The colon of *Tarsius*, which in virtually all details is simpler than that of any other primate, likewise is abbreviated, the ratio usually being less than 0.20 (Von Eggeling, Flower, Jacobshagen, Straus), with extreme avail-

able values of 0.10 (Jacobshagen) and 0.28 (Leche). From these data we may assume that the colon in the fore-runners of the primates, and in the primitive primates as well, was a relatively short organ. Its length probably did not exceed one-fifth that of the small intestine.

In the Lemuroidea, undoubtedly in connection with the development of the distinctive lemurine colic loop, the colon has undergone a comparative prolongation, so that its linear dimensions approach those of the lesser bowel. Yet only in *Perodicticus* does length of colon regularly surpass that of small intestine (Jacobshagen, Straus). Curiously enough, however, in the very closely allied genus *Arctocebus*, the colon/s. i. ratio is but little more than 0.50 (Huxley, cited by Jacobshagen). Not all lemurs, however, have undergone a great relative colic lengthening, for the c./s. i. ratio is less than 0.50 in *Hapalemur* (Beddard, cited by Jacobshagen), in some specimens of *Lemur* (Von Eggeling, Jacobshagen, Leche), all specimens of *Daubentonia* (various authors), and the Indrisinæ—*Propithecus*, *Indris*, *Avahis* (Milne-Edwards & Grandidier). In *Microcebus* and *Cheirogaleus*, judging from Van Loghem's studies and from the accounts given by Le Gros Clark (1934) and Reider, the colon is not relatively long. One might expect that it would be comparatively longest in the Indrisinæ, in which the lemurine colic loop attains its greatest complexity, but in this group apparently the small bowel has lengthened as well.

The few New World monkeys that I have examined exhibit great extremes in relative length of colon. My values, however, are in rather close agreement with the more extensive investigations of Von Eggeling. When the entire group of platyrrhines is considered, some very curious facts appear. Thus the colon is relatively very long in at least one genus of marmosets—*Callithrix*—regularly being more than half the length of the small intestine, whereas in another group of marmosets—*Leontocebus*—it is slightly less than one-third as long as the small bowel. The colon is even relatively shorter in the platyrrhines of the family Cebidæ than in

Leontocebus, the c./s. i. ratio being 0.27 in an *Alouatta*, constantly about 0.20 in *Ateles*, usually between 0.15 and 0.20 in *Cebus*, and around 0.10 in *Saimiri* (see Von Eggeling's data). As a matter of fact, the colon regularly is relatively shorter in the Cebidæ than in any of the other Anthropoidea.

In the monkeys of the Old World the linear ratio between small and large bowel is considerably larger than in the Cebidæ, so that the colon is relatively longer (also see Von Eggeling, Leche, Flower). On occasion it approaches or even surpasses the value found in some of the Lemuroidea. It should be noted, however, that the c./s. i. ratios calculated from the extensive series of langurs (*Semnopithecus* sive *Pygathrix*) studied by Kohlbrügge (1900) all are somewhat less than that obtained in my specimen of *Pygathrix entellus* listed above, most of his ratios being less than 0.30. It therefore is at least possible that the colon is relatively shorter in the subfamily Colobinæ (as represented by *Pygathrix*) than in the subfamily Lasiopyginæ of the catarrhine monkeys.

Turning to the anthropoid apes and man, it will be seen that the colon usually is slightly shorter than in the catarrhine monkeys. For the gibbons, the intestinal measurements of 4 specimens are available (Bischoff 1870, Von Eggeling, Straus). These yield an average colon/s. i. ratio of 0.31, with extremes of 0.20 (Bischoff) and 0.42 (Straus). Relative colon length is 0.36 in the gibbon fetus of Deniker. The data concerning 4 orang-utans, with an average ratio of 0.31, and limits of 0.26 and 0.36, have been listed above. The intestinal lengths of 7 chimpanzees have been gathered from the literature (Von Eggeling, Ehlers, Gratiolet & Alix, Jacobshagen 1930, Sonntag 1923). Adding my specimen, the average c./s. i. ratio is 0.26, with extremes of 0.19 (Von Eggeling) and 0.44 (Gratiolet & Alix). Relative colon lengths have been figured from the measurements of 5 gorillas (Bischoff 1880, Bolau, Jacobshagen 1930). The average c./s. i. ratio is 0.31, with a range from 0.18 (Bolau) to 0.43 (Bolau). The ratio also is 0.31 in Deniker's gorilla fetus.

The two adult men measured by me give an average ratio of 0.26, which is identical with that of the chimpanzee.

Thus it may be concluded that on an average the c./s. i. ratio differs but little among the group of so-called higher primates composed of the four anthropoid apes and man. This ratio averages 0.31 in orang-utan, gorilla and gibbon, and 0.26 in both chimpanzee and man. When one takes into account the individual variability in this proportion, the generic differences appear to be of no real significance.

No definite growth change in the colon/s. i. ratio is apparent in the material discussed, nor does it occur in Kohlbrügge's extensive langur series.

In summary, one is led to conclude that a short colon (relative to small intestine) represents the primitive primate condition, essentially as found in *Tarsius*. In this respect the colon has remained primitive in the New World monkeys of the family Cebidæ. It has lengthened somewhat, but to no very marked degree, in the Catarrhines. The process of colic increase in general is more advanced in the Old World monkeys than in the anthropoid apes and man. In their conservatism as regards colon length, all of the Anthropoidea (excepting only certain marmosets) contrast markedly with the Lemuroidea. The latter are extremely aberrant in respect to this character, for most of them have greatly lengthened the colon. In this tendency they are paralleled by some marmosets and a few Old World monkeys.

Peritoneum

A. Orang-utan.—The ventral mesentery almost completely envelops the liver, so that the "bare area" is extremely small—as was determined from both adult (Fig. 13) and newborn—this being a primitive condition. It forms a lesser omentum extending from the porta hepatis to the lesser curvature of the stomach and the first part of the duodenum.

The greater omentum (omentum majus) in the adult is very extensive and filled with huge masses of fat (Figs. 2 and 7), as are all other parts of the mesentery in this animal. It

extends downward from the greater curvature of the stomach and the very beginning of the duodenum, to become attached not only to the transverse colon, but also to most of the ascending colon and the upper third of the descending colon, along the line of the tenia omentalis. On the left side of the abdominal cavity, lateral to the descending colon, the omentum is adherent to the parietal peritoneum. On the right side, it is herniated into the right scrotal sac, forming a distinct indirect inguinal hernia (Fig. 2, insert). The hernial sac thus formed contains only omentum, no part of the bowel being involved. In the juvenile the omentum is also fused to the serous covering of the transverse colon, but it is not evident from my notes whether there was additional attachment to other parts of the bowel. The greater omentum of the newborn is less extensive than that of the adult (Fig. 3). It is adherent below only to the transverse colon. Little fat is present within its folds.

The arrangement of the peritoneal attachments of the intestine is best illustrated by Fig. 11. The root of the mesentery proper of the jejuno-ileum (mesenterium) extends from the duodenojejunal flexure inferiorly and to the right, to end at the ileocæcal junction. Its course in the adult is directed somewhat obliquely, from the level of the 1st lumbar vertebra—thus about one vertebra higher than in man—near the midline toward the region of the right sacro-iliac articulation. The length of the root is about 15 cm., the same as is usual in man. In the newborn, the root of the mesentery proper lies somewhat more in a sagittal plane, and appears to be relatively shorter. Near its termination the mesentery proper gives rise to a peritoneal fold supporting the vermiform appendix (mesappendix) (Fig. 7, insert).

The peritoneal attachments of the large intestine differ among the three animals. In the adult—in addition to the usual mesocolon transversum and mesocolon sigmoideum—there is a short superior mesocolon ascendens and a rather extensive inferior mesocolon descendens. The juvenile possesses a complete mesocolon; hence there is a complete meso-

colon ascendens, and a complete mesocolon descendens. In the newborn, there is a mesocolon ascendens, but a mesocolon descendens is entirely absent.

The splenic ligaments—phrenicolienal and gastrolienal—are well developed. The phrenicolienal ligament of the adult is very strong. In this animal a distinct phrenicocolic ligament (the so-called sustentaculum lienis) also is apparent.

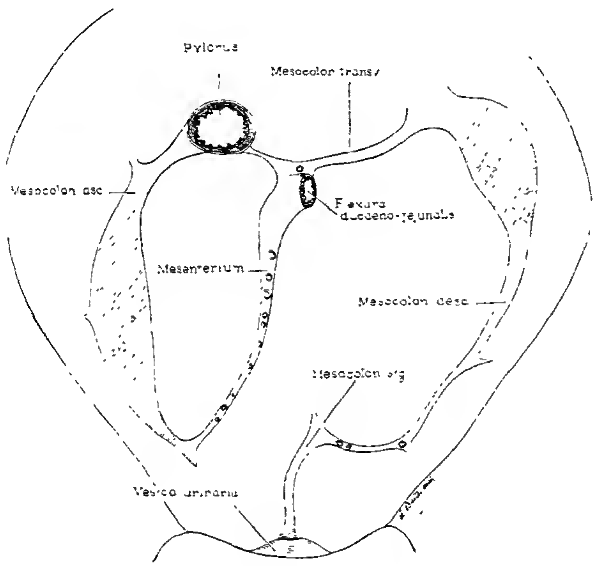

FIG. 11. Plan of the roots of the mesentery in adult male orang-utan (J. H. Anat. no. 212). The shaded areas mark the positions of the retroperitoneal portions of the ascending and descending colons.

The peritoneal fossæ or recesses also present some points of interest. In the adult there is a shallow superior duodenal fossa, much filled with fat, but no inferior duodenal or duodenojejunal fossæ; there are a small but clearly evident superior ileocæcal fossa and a good-sized inferior ileocæcal fossa (recessus ileocæcalis inferior) bounded above by the plica ileocæcalis (see Fig. 7, insert); an intersigmoid fossa is present, but it is relatively shallow. The newborn exhibits a well-marked inferior duodenal fossa, but other recesses are absent around the duodenojejunal junction; both superior

and inferior ileocæcal fossæ are present, the latter being especially well developed, but there is no intersigmoid fossa.

The peritoneal cavity in the orang-utan thus is divided into distinct greater and lesser sacs quite as in man, the latter being entered through the epiploic foramen (of Winslow) behind the lesser omentum.

No separate description of the peritoneum in the orang-utan seems heretofore to have been published, except some remarks by Klaatsch pertaining to an animal afflicted with peritonitis. Some idea of its arrangement may be gleaned, however, from the writings of Anthony and of Sonntag. Their findings apparently do not differ markedly from my own, except that in Anthony's animal both duodenum and pancreas were intraperitoneal in position, lying within the folds of the transverse mesocolon. This latter disposition, however, is almost certainly not the normal one for the post-natal orang, but represents an instance of arrested development; it possibly is associated with the peculiar form and course of the duodenum in Anthony's animal. In two orangs, Reider found that the mesenteric attachments were as in man. The occurrence of an ascending or a descending mesocolon in the orang, judging from my own three specimens and those of Anthony, Sonntag and Reider, is a variable feature as it is in man. These structures, however, possibly occur more frequently in the orang than in man. Thus an ascending mesocolon was present in 4 out of 7 orangs (57 per cent), a descending mesocolon in 3 out of 7 (43 per cent). In man, Treves encountered an ascending mesocolon in 26 out of 100 bodies (26 per cent), a descending mesocolon in 36 out of 100 (36 per cent). Chapman, Klaatsch and Anthony found in their orangs that the greater omentum was fused with the peritoneum of the transverse colon, as in my animals. Anthony encountered superior and inferior cæcal and intersigmoid fossæ, while Klaatsch saw a shallow duodenojejunal fossa.

B. Other Primates.—The classic papers of Klaatsch (1892) and Van Loghem (1904) deal with the comparative anatomy of the peritoneum. That of Van Loghem is the more exhaus-

tive with respect to the primates and has been largely followed here. In *Tarsius* there is a primitive common dorsal peritoneal fold or mesintestinum for the entire bowel. Essentially the same arrangement is to be noted in the tree-shrew *Tupaia*. Notwithstanding the complexity of the colon in many of the Lemuroidea, the peritoneal attachments remain relatively simple (Fig. 12, *A*), and no portion of the bowel is in a retroperitoneal position.

The chief change in the monkeys of the New World concerns the mesoduodenum, which has become shortened or

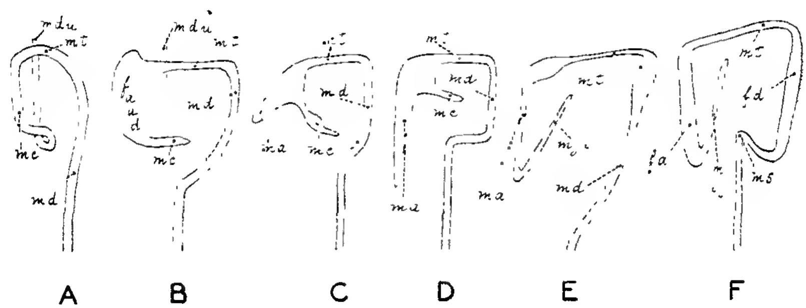

FIG. 12. Plans of the roots of the mesentery in (*A*) *Galago crassicaudatus;* (*B*) New World monkeys; (*C*) "Cercocebus-type"; (*D*) "Cercopithecus-type"; (*E*) *Hylobates* (= *Symphalangus*) *syndactylus;* (*F*) Chimpanzee. After Van Loghem (1904). *fa* = course of ascending colon, which is retroperitoneal; *faad* = field of attachment of ascending colon to duodenum; *fd* = course of descending colon, which is retroperitoneal; *ma* = ascending mesocolon; *mc* = common mesentery of jejuno-ileum and ascending colon; *md* = descending mesocolon; *mdu* = mesoduodenum; *mji* = mesenterium (mesentery of jejuno-ileum); *ms* = sigmoid mesocolon; *mt* = transverse mesocolon.

even practically obliterated, so that in some specimens the duodenum proper and pancreas have become secondarily retroperitoneal (Van Loghem, Straus). A definite transverse mesocolon (Fig. 12, *B*, *mt*) now is well-differentiated, and the entire large intestine still is supported by folds of peritoneum, although the ascending colon may be adherent to the duodenum (Fig. 12, *B*, *faad*) (Van Loghem). In such an arrangement the ascending colon, although not actually retroperitoneal in position, does not possess a free peritoneal ligament. Reider, however, in *Cebus* and *Lagothrix*, found that while the

right colic flexture is tied down to the duodenum, at least a small mesocolon regularly is present.

In the Old World monkeys the mesoduodenum normally has disappeared completely, the transverse mesocolon is well-defined, and there are the beginnings of a separate or secondary fold of peritoneum for the support of the ascending colon (Fig. 12, *C* and *D*, *ma*) (Van Loghem).

This secondary ascending mesocolon evolves from the primitive mesentery common to the jejuno-ileum and the first part of the proximal colon (and cæcum) (Fig. 12, *A*, *B*, *C*, *D*, *mc*). The development of a separate ascending mesocolon most probably is associated with the more complete rotation of the cæcum and the first part of the proximal colon. Van Loghem noted the rudiments of a separate or secondary mesocolon ascendens in such monkeys as *Cercocebus* (Fig. 12, *C*, *ma*), while the process was far advanced in forms like *Cercopithecus* (= *Lasiopyga*) (Fig. 12, *D*, *ma*), and in certain respects even more highly developed in some members of the Colobinæ. The entire colon normally is intraperitoneal, but I have noted that some fixation in the region of the hepatic flexure is not rare (also cf. Reider). In the catarrhine monkeys studied by Reider, fixation of at least a part of the ascending colon was of frequent occurrence.

The conditions in the four anthropoid apes and man fundamentally are identical (Figs. 11 and 12, *E* and *F*). The duodenum of course is retroperitoneal in position, the transverse mesocolon (Fig. 12, *E* and *F*, *mt*) is long and well-developed, and the formation of a separate ascending mesocolon (Fig. 12, *E*, *ma*) is completed. Associated with the latter development is the formation of a secondary mesentery for the jejuno-ileum (Fig. 11, mesenterium; Fig. 12, *E* and *F*, *mji*), a structure peculiar to the apes and man. Coincident with the great development of a sigmoid or omega flexure, the corresponding portion of the mesocolon is relatively long (Figs. 11 and 12, *F*). In these animals there is a progressive tendency for the ascending and descending parts of the colon to lose their supporting folds of peritoneum and become fixed

to the posterior body wall (Fig. 12, *F*, *fa* and *fd*). The individual variability is quite considerable. The beginnings of this process are clearly to be seen in the gibbons. Thus, in an adult *Hylobates leuciscus,* I found that the ascending colon was entirely retroperitoneal in position, while both the whole descending and sigmoid colons possessed a long, free mesocolon. In the Hylobatidæ, complete peritoneal ligaments for the ascending and descending parts of the colon, especially the former, likely are of less frequent occurrence than in the monkeys. The degree of colic fixation usually is even more advanced in the great apes, while complete adhesion is the normal condition for man (cf. Van Loghem, Reider). In the last-named both the ascending and descending segments of the large bowel usually are completely retroperitoneal in location.

According to the investigations of Treves, cited above, the descending mesocolon is of more frequent occurrence in adult man than is the ascending mesocolon. Treves pointed out that this discrepancy in frequency is to be expected, for whereas the ascending mesocolon is a secondary development, the descending mesocolon is a primitive structure that is extensive and conspicuous in monkeys and other mammals. In support of Treves' reasoning I need refer only to the aforementioned phylogenetic conservatism of the distal colon.

The phylogenetic fixation of the colon is sometimes (*e.g.* by Keith, 1933) ascribed to the assumption of an upright or orthograde posture. Justification for such a conclusion, however, is by no means certain. The gibbon, for example, probably holds its trunk more completely erect—and this for a greater proportion of the time—than does the gorilla, yet available evidence would seem to indicate that the process of colic fixation on the whole is more advanced in the latter animal. The factors involved probably are too complex to permit such a simple explanation.

It has been claimed by Chapman (1879, '80) that the greater omentum in monkeys is not fused with the peritoneum of the transverse colon—except in a rudimentary way in some

macaques—this being the condition found in the early human fetus. He furthermore pointed out that adhesion of the omentum with the transverse colon occurs, however, in the chimpanzee and the orang-utan as it does in man. The findings of Chapman on monkeys do not entirely agree with my own and those of other workers. The beginnings of such omento-colic adhesion are to be noted even in the Lemuroidea (Klaatsch, Van Loghem, Reider, Straus), and the degree of fusion may be rather extensive. In a specimen of *Lemur variegatus*, for example, I found that the omentum was adherent to the colic coils and was attached even to the tip of the cæcum, yet there was no evidence of a peritonitis or other inflammatory process (also see Reider). In Old World monkeys, the omentum may be fused with the colon in a variety of ways: (1) to the hepatic flexure and the adjacent portion of the transverse colon (Van Loghem), (2) to the transverse colon, as I found in a *Lasiopyga callitrichus* and a *Cercocebus lunulatus*, (3) to both the transverse and ascending colons (Duckworth, Straus)—in a juvenile female *Erythrocebus patas* I noted that the omentum was connected only slightly with the transverse colon, but strongly to the ascending colon, (4) to the hepatic flexure, ascending colon and cæcum (Huntington, Reider), (5) to most of the colon, as in an infant male *Erythrocebus patas* that I examined, or (6) the adhesion may be relatively slight, so that the omentum can be traced back to the posterior body wall, as I saw in a *Macaca mulatta*. In the four anthropoid apes and man the omentum appears regularly and normally to be fused only with the transverse colon, yet other colic adhesions probably are not entirely the result of pathological conditions.

Liver

A. Orang-utan.—The liver (*hepar*) of the orang-utan quite closely resembles that of man. It is composed of right and left lobes and a Spigelian (papillary and caudate) lobe complex.

The adult liver is a huge organ, occupying the better part of the region immediately inferior to the diaphragm (Figs. 2

and 13). Its weight is 3025 g. (formalin fixation). The right lobe is considerably larger than the left. The latter lobe, however, is also well-developed, swinging far to the left of the midline so as almost completely to cover the stomach. The quadrate lobe or lobule, which in reality is but the lower left portion of the right lobe, is relatively quite small. The Spigelian complex, however, is comparatively very large, being of considerably greater relative size than in man. Of

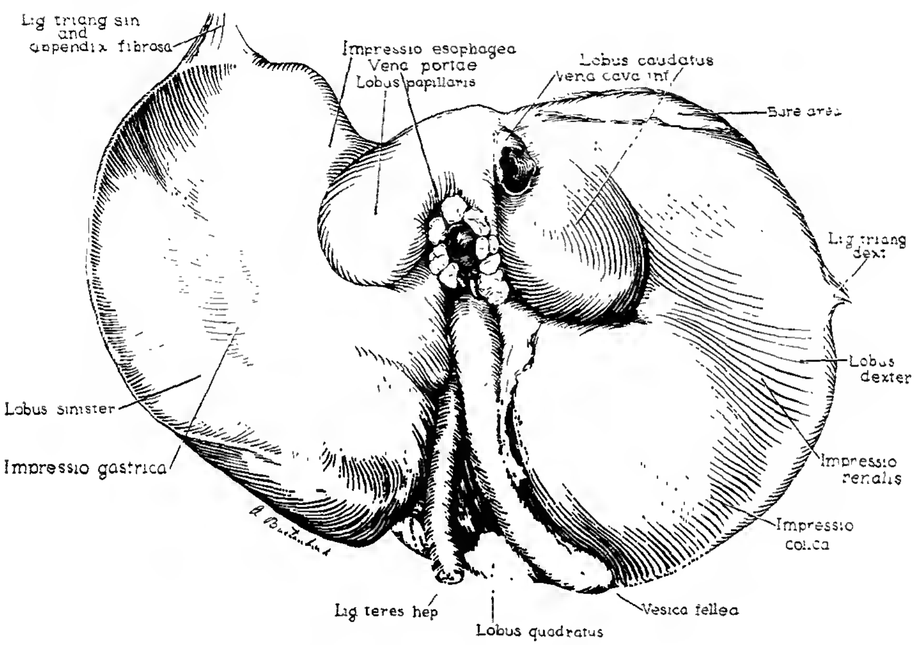

FIG. 13. Dorsal aspect of the liver of adult male orang-utan (J. H. Anat. no. 212).

this complex, the papillary lobule is very well-developed, and its inferior projection—the papillary process—is especially conspicuous. The papillary lobe is connected to the second portion of the Spigelian complex, the caudate lobule, by the caudate process. The caudate lobule itself is relatively huge. Minor fissuration or lobulation within the liver is lacking. There is a well-marked gastric impression on the left lobe, and a shallow esophageal impression. On the right lobe both

renal and colic impressions are fairly conspicuous, but there is no definite duodenal impression. The dorsal surface of the inferior vena cava is bridged by a thin layer of hepatic tissue connecting the papillary lobule and the right lobe proper. The long and narrow gall-bladder (vesica fellea) occupies a well-marked depression; when the abdominal cavity is first opened this organ is just visible below the inferior margin of the right lobe. The liver is almost completely invested by the ventral mesentery, so that only a very small "bare area" is apparent along the upper margin of the right lobe; the leaves of the coronary ligament thus approach one another quite closely. Both left triangular ligament and the associated appendix fibrosa are well-developed, but the right triangular ligament, which is located midway along the lateral margin of the right lobe, is small. The round ligament, which courses along the lower border of the strong falciform ligament, is imbedded within a great mass of fat. Its uppermost portion occupies a relatively deep umbilical fossa.

The liver of the juvenile orang-utan presents the same general features as that of the adult, although a few minor differences exist. The left lobe is relatively smaller than in the adult. The quadrate lobe is relatively larger and the adjacent umbilical fissure quite deep. The Spigelian complex is comparatively larger than in man, and the papillary process is directed to the left instead of pointing caudally as it does in the human liver; the caudate process is quite large, but relatively smaller than in the adult orang. As in the adult, the posterior aspect of the inferior vena cava is bridged by hepatic tissue connecting the papillary and right lobes. But one small accessory lobule, located on the posterior surface of the right lobe below the caudate lobe, is apparent. Liver weight is 507 g. (formalin fixation).

The liver of the newborn orang-utan seems relatively smaller than that of the human newborn (Figs. 3 and 14, *A*). The right lobe is very much larger than the left, approaching twice its bulk. That the left lobe is not as relatively well-developed as in the adult orang is also apparent by the fact

that it does not hide as much of the stomach. Yet the gastric impression is quite marked. The quadrate lobe is relatively of great size. As in both adult and juvenile, there is a large Spigelian complex, of which the papillary and caudate portions, especially the former, are exceedingly prominent and independent. Also as in the two older specimens, the inferior vena cava is surrounded by hepatic tissue. Minor fissures and lobules are entirely absent; this is in striking contrast to the liver of newborn man. The elongated gall-bladder lies in

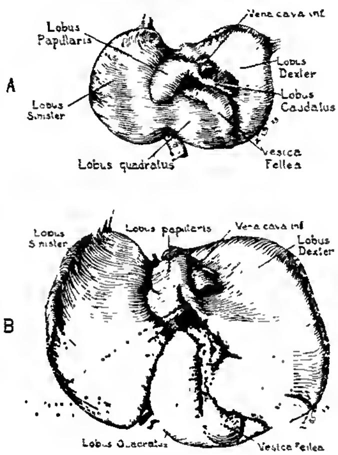

FIG. 14. Dorsal aspects of the livers of (*A*) newborn female orang-utan (U. S. N. M. no. 153825) and (*B*) newborn female Negro. In *B*, note the persistent fissure to the right of the gall-bladder, dividing the right lobe into its primitive lateral and central components.

a well-marked depression. A very small "bare area" is present along the cranial margin of the right lobe. The left triangular ligament is strong, the right rather weak. There is no appendix fibrosa. A true umbilical fissure or fossa does not occur, for the round ligament plunges directly into the liver at its caudal margin. Liver weight is 55 g. (alcoholic fixation).

The literature contains numerous descriptions of the livers of individual orang-utans. Many of these data have been collected by Ruge (1902–08) and incorporated in his

classic monograph on the gross morphology of the primate liver. Here he likewise described, in almost exhaustive detail, the livers of seven orangs. All writers agree that the liver of the orang is strikingly human in its general form. The structural variations are of an essentially minor character (for details see Ruge). But three true lobes—left, right, Spigelian—are present, and these are quite well fused, minor fissuration or lobulation being neither common nor extensive. Hence the boundaries between the central and lateral lobes of lemurs and monkeys normally are completely obliterated. Yet a cleft in the right lobe indicating the privitive division between the right central and right lateral lobes may occur at times; occasional minor fissures likewise may indicate similar primitive boundaries in the left lobe. A small parumbilical lobule, adjacent to the ligamentum teres, is not extremely rare. Of the Spigelian complex, the caudate lobule tends toward reduction and fusion with the right lobe proper, but the papillary lobule is better developed than in man. This latter arrangement represents a primitive condition. On the other hand, the left lobe exhibits signs of reduction relative to the right lobe, this being a progressive primate feature. The gall-bladder, which is elongated and narrow, occupies a distinct groove or fossa. The inferior vena cava usually is surrounded by hepatic tissue. Development of an umbilical fossa or fissure is variable. The "bare area" may be quite extensive. From the preceding account, which is derived mainly from Ruge, it is apparent that the livers of the three orang-utans studied by the present writer may be regarded as quite representative of this genus of anthropoid ape. Their differences are to be regarded as individual variations, and not as growth changes.

B. Other Primates.—The gross morphology of the liver in the various families and genera of primates has been so thoroughly investigated by Ruge (1902–08) that but little remains to be added. For the purposes of orientation and comparison, however, the following phylogenetic survey is

given. This is derived partly from Ruge's publications, from other sources, and from my own studies in addition.

The essentially primitive mammalian structure of the liver may be seen in the Lemuroidea, particularly in such forms as *Perodicticus*, *Nycticebus* and *Loris* (Fig. 15, *A*). Four major lobes are apparent: Left lateral, central—which is divided into left and right parts by the umbilical fissure or incisure and in some instances by an interlobular fissure—right lateral and Spigelian—which is formed of two components, a caudate and a papillary, the latter being relatively small, while the former attains relatively huge proportions. As pointed out by Anthony and Villemin (1923), the caudate element of the Spigelian complex is very long, extending caudally between kidney and duodenum—thus occupying the retroduodenal space—in those primates (lemurs and platyrrhines) in which a mesoduodenum persists. In those forms in which the duodenum becomes fixed, the caudate lobule is reduced. This strongly suggests a definite correlation between the development of this lobule and the position of the duodenum. Of the four major lobes in the Lemuroidea, the left lateral, which swings far to the right side of the body, is the largest, being followed in size by the central, the right lateral, and the Spigelian. A considerable amount of minor lobulation may be apparent; this probably is a primitive feature, although the validity of such an interpretation has been questioned by Le Gros Clark (1934). There is a deep notch or incisure for the esophagus. The posterior surface of the inferior vena cava is bridged by hepatic tissue, so that this vessel actually pierces the liver. The body of the gall-gladder can be seen from the ventral or diaphragmatic aspect of the liver through a large cleft in the right portion of the central lobe. The liver is so completely invested by the peritoneum of the ventral mesentery that a so-called "bare area" is not formed. Differences between the various genera of lemurs would seem to be of relatively minor character, and all available members of the suborder adhere to the general description given above.

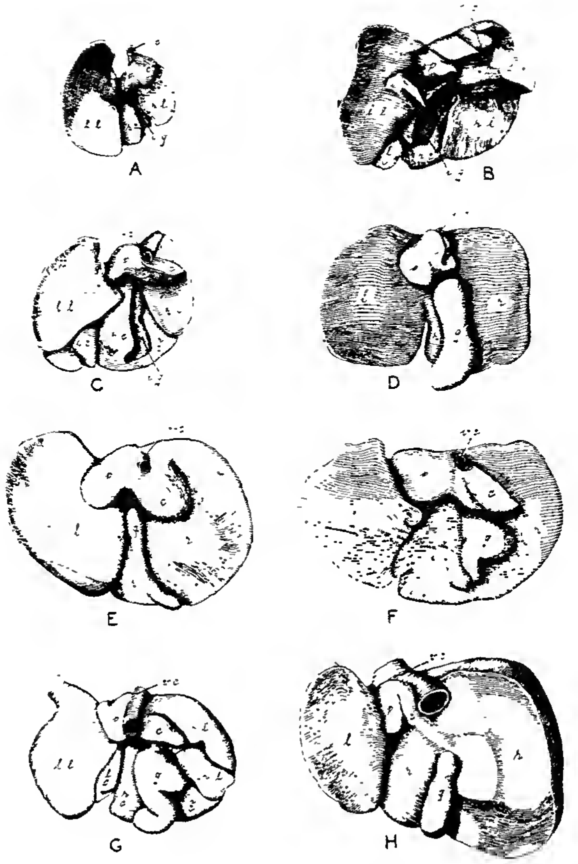

FIG. 15. Dorsal aspects of the livers of (*A*) *Nycticebus tardigradus* (= *N. coucang*); (*B*) *Cebus capucinus*; (*C*) *Macaca nemestrinus*; (*D*) *Hylobates leucogenys* (J. H. P. A. L no. 73); (*E*) Orang-utan, adult male (J. H. Anat. no. 212); (*F*) Chimpanzee (J. H. Anat. no. 162); (*G*) Gorilla; (*H*) Man. *A*, *B* and *C* are after Ruge (1902–08), *G* is after Duckworth (1915), and *H* is after Spalteholz. *c.* = caudate lobule; *g.* = gall-bladder; *i. g.* = impression for gall-bladder; *l.* = lateral lobe of anthropoid apes and man (composed of fused primitive left lateral and left central lobes); *l. c.* = left central lobe; *l. l.* = left lateral lobe; *p.* = papillary lobule; *r.* = right lobe of anthropoid apes and man (composed of fused primitive right lateral and right central lobes); *r. c.* = right central lobe; *r. l.* = right lateral lobe; *v. c.* = inferior vena cava. Note the primitive fissuration in the gorilla, and the tendency toward minor lobulation in the chimpanzee. In this specimen of gorilla, the vena cava is bare on its dorsal surface. The left central lobe of *Nycticebus* is not visible, it being covered from this aspect by the left lateral lobe.

The liver of *Tarsius* differs considerably from those of the Lemuroidea and in some respects resembles those of the Anthropoidea, as Duckworth (1915) already has shown. Thus while the lobar formula is still LL > C > RL > S, the lobation is not so well marked as in lemurs, the esophageal incisure is relatively shallower, the body of the gall-bladder is not exposed ventrally, and the Spigelian complex is of different form—the caudate portion is rather smaller, while the papillary element is quite large and fits into the lesser curvature of the stomach.

Some changes in hepatic form can be noted in the New World monkeys (Fig. 15, *B*). Thus the right lateral lobe is now larger than the left lateral, and may be the largest lobe of the liver, although in some forms—as *Saimiri sciureus*—it in turn may be surpassed by the central lobe. The Spigelian complex still is very large. A considerable amount of minor lobulation may be present—as in *Saimiri*. The esophageal impression still is quite deep, and the inferior vena cava usually is bridged posteriorly by liver tissue; in both of these features the liver of *Ateles* appears to be an exception (cf. Ruge), this genus herein paralleling the more advanced Old World forms, as it does in many other morphological details. The body of the gall-bladder is unexposed from in front. A small "bare area" may be present—as in a marmoset examined by me—but this probably is of exceptional occurrence.

Many of these changes are carried further, also with considerable variability, in the Old World monkeys of the subfamily Lasiopyginæ. The four primitive lobes still are apparent (Fig. 15, *C*). The right lateral lobe is relatively large, so that it may surpass the left lateral in size, though not always. The Spigelian lobe is somewhat reduced, but still relatively large; this lobe apparently is quite variable in form, *e.g.* I find the caudate element to be much reduced in *Erythrocebus patas*, while it is the papillary element that is rather small in *Macaca mulatta*. Minor lobulation is quite common. The depth of the esophageal incisure varies, but tends toward

reduction; according to Duckworth, it is relatively shallower in the baboons than in other cercopithecine (= lasiopygine) forms. The inferior vena cava regularly is surrounded by hepatic tissue. The body of the gall-bladder is not exposed from in front—in one specimen of *Macaca mulatta*, however, I noted that this organ was so exposed, though not as extensively as in lemurs. A "bare area" is not rare, especially in the macaques and baboons (cf. Ruge).

In the Old World monkeys of the subfamily Colobinæ the liver is so altered in form that it is vastly different from the corresponding organ of any other primate. Indeed, Duckworth (1915) went so far as to state that the colobine liver "is modified to an extent rendering it unrecognizable as that of a primate animal." Because of the enormous development of the stomach in these monkeys, the liver is displaced far to the right. In a fully adult male langur, *Pygathrix entellus*, examined by me, the liver was relatively small, and was lobulated to a degree far greater than that exhibited by any other catarrhine monkey examined. This lobulation is scarcely a primitive feature, but probably is correlated with the peculiar gastric morphology.

The livers of the anthropoid apes are characterized by a reduction in lobation. Keith (1899) believed this reduction to be the result of an erect posture, but this probably is an unwarranted assumption, in view of the conditions occurring in the gorilla (vide infra). The central lobe has disappeared as a distinct element, its left and right portions having fused with the adjacent lateral lobes to form the left and right lobes of the apes and man. The boundary between the left and right lobes therefore represents the dividing line between the two portions of the old central lobe. This description is true only of the gibbons, the orang and the chimpanzee (Fig. 15, *D*, *E*, *F*), for, as is well known, the liver of the gorilla (Fig. 15, *G*) always exhibits many fissures and consequent subdivision of the lobes. According to Flower (1872), the gorilla liver distinctly shows the primitive left and right lateral and subdivided central lobes. Leaving aside the aberrant and

primitive liver of the gorilla, the livers of the other anthropoids are featured by the increasing development of the right lobe, which consistently surpasses the left in size, although there is a considerable variability in this relation, as in the orang. Thus in a *Hylobates leuciscus* the weight of the right lobe was three times that of the left one. This predominance of the right lobe is a progressive feature. Minor lobulation is relatively slight, but may occur (cf. Fig. 15, *F*). There is a relative reduction of the Spigelian lobe—more particularly the caudate element—when comparison is made with monkeys. This character, however, is quite variable, so that a large, free caudate lobule is a not uncommon occurrence in the gorilla, chimpanzee and orang-utan (see Fig. 15, *F*). The reduction of the caudate lobule is by far most marked in the gibbons. In a specimen of *Hylobates leucogenys* (Fig. 15, *D*) at hand, the Spigelian complex is quite human in size and form—although the papillary element is of rather good size, the caudate element is vestigeal and scarcely apparent. Similar regression of the caudate component can be seen in a *H. leuciscus*. The same condition in other Hylobatidæ has been noted by both Flower and Ruge. The esophageal impression tends to be proportionally shallower than in the monkeys, this process being most advanced in the orang-utan. The umbilical fissure may be strongly marked at its free edge in the gibbons. In the orang, chimpanzee and gorilla, the posterior surface of the inferior vena cava usually is bridged by hepatic tissue, so that this vessel actually pierces the liver. This is a primitive condition. In the gibbons, however, the vena cava nearly always is bare upon its posterior aspect; in this respect, therefore, as with the Spigelian lobe, the Hylobatidæ are considerably more advanced than the other anthropoid apes. The body of the gall-bladder is unexposed ventrally. A definite "bare area" usually is present, and this may be quite extensive in the three great apes.

The human liver (Fig. 15, *H*) greatly resembles those of the gibbon, orang and chimpanzee. Left, right and Spigelian

lobes can be recognized. The right lobe, however, is even relatively larger than in apes. There is a further relative diminution of the Spigelian complex, especially the caudate portion. The latter lobule is enormously reduced, chiefly in its caudal portion, where it is continuous with the right lobe through the so-called caudate process. Minor lobulation is uncommon. Traces of the fissure between the primitive right lateral and right central lobes frequently occur, however, in the newborn human liver (Keith, 1933) (also see Fig. 14, *B*). The esophageal impression is relatively shallow, as in the anthropoid apes. The inferior vena cava normally is not surrounded by liver tissue, and the body of the gall-bladder is unexposed ventrally. There is a constant and considerable "bare area."

In closing this survey of the liver, mention must be made of the curious resemblance of the gibbon liver to that of man. The livers of my *Hylobates leucogenys* and *H. leuciscus* are more man-like in their general configuration than that of any other ape (orang, chimpanzee), monkey, tarsier or lemur that I have studied. A somewhat similar conclusion was reached by Flower (1872). In regard to the livers of two specimens of *Hylobates lar*, he stated (p. 394) that "in general form and proportions of the principal parts they both show a great resemblance to the human liver—perhaps more than any of the preceding forms (chimpanzee, gorilla, orang-utan)."

The weight of the adult liver averages 13.2 times that of the newborn liver in the langur, *Pygathrix* (Kohlbrügge), 12.8 times in Europeans (Vierordt, 1906), and 11.6 in Filipinos (De Jesus, De Leon et al., 1933). The agreement of these figures is most striking. The value for my orang-utan series cannot be compared, because of the pathological processes encountered in the liver of the adult animal.

Pancreas

A. Orang-utan.—This gland greatly resembles that of man. It is not composed grossly of two separate parts. Located retroperitoneally, it lies in the curvature of the duodenum,

extending toward the spleen. In the adult it crosses the vertebral column at about the level of the last (12th) thoracic and 1st lumbar vertebræ, in the newborn at about the level of the last (12th) thoracic vertebra. The pancreas thus lies slightly more cranially than it does in man. All three animals exhibit a main pancreatic duct (of Wirsung), while the adult shows an accessory pancreatic duct (of Santorini) in addition. The intestinal relations of these ducts have been described with the duodenum. Pancreas weight is approximately 129 g. (formalin fixation) in the adult, 2 g. (alcoholic fixation) in the newborn. The pancreas weight of the adult thus is 64.5 times that of the newborn.

Anthony found the pancreas of his orang-utan to be like that of man; it exhibited only one duct. In Cunningham's animal it lay in relation to the 11th and 12th thoracic and 1st lumbar vertebræ, a topographic arrangement that did not differ markedly from those encountered by me in the adult and newborn specimens.

B. Other Primates.—The pancreas exhibits no phylogenetic changes of particular interest within the primates. The peritoneal relations parallel those of the duodenum. In a specimen of *Lemur variegatus* I found that the two parts homologous to the head and tail of the human pancreas were almost completely autonomous. The superior mesenteric artery and vein passed between the two portions, which were connected merely by a narrow bridge of pancreatic tissue lying dorsal to the blood vessels. The pancreas also exhibits two distinct parts in *Tarsius* (Woollard).

The weight of the adult pancreas averages 62.6 times that of the newborn pancreas in the langur, *Pygathrix*, (Kohlbrügge, 1900), but only 27.8 times in Europeans (Vierordt, 1906) and 33.4 times in Filipinos (De Jesus, De Leon et al., 1933). The difference between monkey and man is enormous. In view of the close agreement between the values for the langur (62.6) and the orang-utan (64.5), and their great contrast to those for the two human groups, one is tempted to conclude—at least tentatively—that for some unknown

reason the pancreas undergoes a relatively greater postnatal weight increase in langur and orang than it does in man. This point would bear further investigation. Furthermore, it seems quite apparent—in monkey, ape and man—that the relative postnatal increase in weight is very much greater in the pancreas than in any of the other solid abdominal viscera.

Spleen

A. Orang-utan.—This organ *(lien)* is situated in the upper left portion of the abdominal cavity, in close proximity to the greater curvature of the stomach (Fig. 3). It is enveloped in folds of the peritoneum. In form it greatly resembles the human spleen, though perhaps it is relatively more elongated, especially in the newborn orang. The usual diaphragmatic, gastric and renal surfaces are apparent, but there is no definite colic impression at the inferior extremity. The peritoneal investment gives rise to the usual splenic ligaments: phrenicolienal and gastrolienal, the former of which is especially strong in the adult. There likewise occurs, at least in the adult, a phrenicocolic ligament (sustentaculum lienis), which runs from the diaphragm to the splenic flexure of the colon. Spleen weight is 525 g. in the adult (formalin fixation), 83 g. in the juvenile (formalin fixation), and 10 g. in the newborn (alcoholic fixation). The spleen of the adult clearly is pathological, which may account for its relatively great weight.

The spleen of the orang-utan generally is rather elongated, as in my examples (Anthony, Hartmann, Wood-Jones). Chudzinski, however, mentioned that it was small and of ovoid form in his adult male, while Hartmann observed that it is shorter and wider than in the other anthropoid apes. Both Anthony and Sonntag (1924 *a*) remarked on the absence of fissures.

B. Other Primates.—Klaatsch (1892) believed that the primitive mammalian spleen was composed of three lobes—anterior, middle and posterior—such as he encountered in the

monotremes, and that the separate lobar elements are recognizable, at least to some degree, in the spleens of primates.

According to Retterer and Neuville (quoted by Anthony and Villemin, 1923), the spleen of lemurs and platyrrhines is more elongated, flatter, and more accommodated to the greater curvature of the stomach than it is in catarrhines. With this conclusion my own observations agree. In the lemurs the spleen is quite elongated and generally fusiform. In one example of *Lemur variegatus*, while the organ is long and narrow, it is nevertheless extremely crescent-shaped (on this point, also see Duckworth). Woollard (1925) found that *Tarsius* possessed a spleen that was long and very narrow, and shaped "like a scimitar." This suggests the condition in *Lemur variegatus*. The spleen of New World monkeys also is markedly elongated. Wood-Jones (1929), however, pointed out that this organ in *Ateles* is shortened, and is not tongue-shaped as in the marmosets, but is almost pyramidal in form. In the Old World monkeys the spleen is less elongated than in lemurs and platyrrhines, and tends to approach—but does not attain—the human form. It definitely is tetrahedral as it is in man, but the borders of the four surfaces seem usually to be sharper and thus better marked. In the proboscis monkey, *Nasalis*, which is a member of the Old World sub-family Colobinæ, the spleen, according to Duckworth, is displaced and is of peculiar form. This probably is correlated with the enormous development of the stomach is these animals. The spleen in the four anthropoid apes closely resembles that of man, but in some examples at least it tends to be more elongated or tongue-shaped, and therein more closely resembles the corresponding organ of the catarrhine monkeys (*e.g.*, see Duckworth, 1915, on the gorilla, and Wood-Jones, 1929, on the orang and gibbon). The human spleen usually is relatively shorter than in other primates, but its variability of form is notorious.

Accessory or supernumerary spleens, presumably the result of a splitting of the lienal anlage, are not exceedingly rare in man. This condition has been encountered by Sonn-

tag (1923) in a chimpanzee, by Woollard (1925) in *Tarsius*, and by me in a *Saimiri sciureus*, in which the accessory organ was of considerable size.

The weight of the adult spleen averages 9.3 times that of the newborn spleen in the langur, *Pygathrix* (Kohlbrügge, 1900), 15.3 times in Europeans (Vierordt, 1906), and 16.8 times in Filipinos (De Jesus, De Leon et al., 1933). The data for the orang are inadmissable, because of the diseased condition of the adult organ.

Kidneys

A. Orang-utan.—The kidneys of the orang-utan closely resemble those of man in outer form. There is no evidence of external lobulation, though in the newborn a shallow furrow tends to divide the organ into cranial and caudal segments (Fig. 16, *O*). Location is entirely retroperitoneal.

In the adult orang-utan, the right kidney is situated slightly caudal to the left. The former organ, which is 9 cm. long, extends from the lower border of the last (12th) rib, opposite the 12th thoracic vertebra, to a point located 1 to 2 cm. below the crest of the ilium. The left kidney, measuring 9.5 cm. in length, extends from the lower border of the 11th rib, opposite the 11th thoracic vertebra, to the level of the iliac crest. In man, the relations of the cranial poles are quite similar, but the caudal poles normally do not reach the iliac crests. In the juvenile orang, the left kidney is slightly caudal to the right. The kidneys of the newborn orang lie at the same level. They extend from the 11th rib, opposite the 12th thoracic vertebra, to just below the crest of the ilium.

In its internal structure, the kidney of the orang contrasts markedly with that of man (see Straus, 1934). Each kidney of all three animals possesses but a single pyramid and a single papilla. The medulla proper is subdivided into three to five parts (secondary pyramids) by short inward extensions of the cortex (false renal columns or septa pyramidis). The papilla is barely indicated in the adult, is better developed in the juvenile, especially in one kidney, and is quite prominent in the newborn. There is no division of the renal pelvis.

Kidney weights are as follows: Adult (formalin fixation)—Left 141 g., Right 135 g.; Juvenile (formalin fixation)—Left 66 g., Right 65 g.; Newborn (alcohol fixation)—Left 5 g., Right 5 g. The combined weight of the adult kidneys thus is 27.6 times that of the newborn kidneys.

Sonntag (1924 *a*) found the right kidney to lie caudal to the left. The kidneys of the adult male studied by Chudzinski were described as being triangular and remarkedly small.

The literature pertaining to the internal structure of the kidney in the orang has been discussed by me in a separate communication (Straus, 1934). There uniformly is but a single true medullary pyramid and a single papilla of variable form, although one specimen described by Mijsberg (1923) apparently possessed two true pyramids and papillæ.

B. Other Primates.—In *Tupaia, Tarsius* and the lemurs the left kidney is situated somewhat caudal to the right kidney. The same relations obtain in New World monkeys, although the discrepancy in level is not as marked. It sometimes is stated that the right kidney is the more caudal in Old World monkeys. In agreement with Wood-Jones (1929), however, I find that the left kidney regularly is lower than the right, and in some animals—as in *Erythrocebus patas* and *Macaca mulatta*—the discrepancy may be very marked indeed. In the four anthropoid apes and man the right kidney normally is the more caudal of the pair, this displacement possibly resulting from the development of the right side of the liver. Yet the relations may be variable, as I have noted above for the orang-utan, so that the topographical conditions found in the monkeys may at times be duplicated.

The chief points of interest relating to internal renal architecture revolve about the aberrant conditions found in man and the spider monkey (*Ateles*). This has been treated by me in detail elsewhere (Straus, 1934). The human kidney regularly possesses many true pyramids and papillæ, a condition occurring only in *some* examples of *Ateles*, and possibly on occasion in the orang-utan as well. As far as is known at the

present time, all other primates—and this includes the anthropoid apes—have kidneys with but one true pyramid, and thus but one true papilla, although the papilla is variable in form and even may be lacking. It is impossible, at the present time, to decide which form of kidney is the more primitive one.

In man, as is well known, the fetal—and even newborn—kidney is highly lobulated externally, resembling, at least superficially, the adult kidneys of certain mammals (Fig. 16, *M*). As I have indicated elsewhere (Straus, 1934), this external lobulation seems not necessarily to be correlated with an internal lobulation, *i.e.* division of the renal medulla into true pyramids. Conditions are different in other catarrhine primates. Anthony and Villemin (1923) found that the surface of the kidney was regularly smooth in fetuses of the rhesus monkey, *Macacus rhesus* (sive *Macaca mulatta*) (Fig. 16, *R*) and the chacma baboon, *Papio porcarius*, near term. In the gibbon fetus studied by Deniker (1886), the surface of the right kidney apparently was smooth (his Pl. XXX, Fig. 11), whereas the left kidney, as figured, exhibits surface markings that may be interpreted as indications of some external lobulation. The kidneys of my newborn orang-utan were smooth, except for a shallow furrow extending laterally from the hilus (vide supra, and Fig. 16, *O*). In the kidneys of both a chimpanzee fetus (Fig. 16, *C*) and a gorilla fetus (Fig. 16, *G*), Anthony and Villemin encountered a restricted superficial lobulation bordering a fissure that—as in my newborn orang—was prolonged laterally from the hilus; the lobulation was somewhat more marked in the gorilla. The fetal gorilla described by Deniker possessed kidneys that were lobulated externally much as in the human fetus, but the lobules were fewer in number; yet internally the kidneys of this particular animal were undivided, exhibiting but a single true pyramid (see Straus, 1934). These data would seem to indicate that the early ontogenetic external lobulation of the kidney in primates is not necessarily related to an internal lobulation, for I have shown (1934) that all four of the an-

thropoid apes regularly possess kidneys that are undivided internally. Furthermore, if it be assumed that superficial renal lobulation is an early ontogenetic feature of primates—and the available evidence indicates that such an assumption probably is warranted—we may conclude that the kidney reaches its essential adult external form at an earlier developmental stage in the Old World monkeys, as exemplified by *Macaca* and *Papio*, and the anthropoid apes than it does in man. This conclusion is in agreement with other data relating to comparative rates of development in monkeys, apes and man.

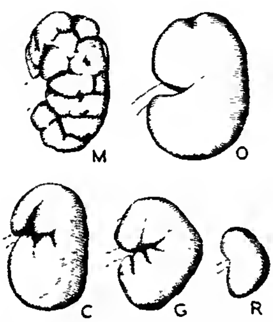

FIG. 16. Surface of the kidney in (*M*) human fetus of 8 months, (*O*) newborn female orang-utan (U. S. N. M. no. 153825), (*C*) chimpanzee fetus, (*G*) gorilla fetus, and (*R*) rhesus monkey (*Macacus rhesus* sive *Macaca mulatta*) fetus. *M*, *C*, *G* and *R* are after Anthony and Villemin (1923).

The weight of the adult kidneys averages 6.8 times that of the newborn kidneys in the langur, *Pygathrix* (Kohlbrügge, 1900), 13.1 times in Europeans (Vierordt, 1906), and 9.5 times in Filipinos (De Jesus, De Leon et al., 1933). The figure for the orang-utan (27.6) is much larger.

ADRENALS

A. Orang-utan.—No adrenal glands were encountered by me in the adult orang-utan. Two possible explanations present themselves, namely—either these structures somehow were overlooked, or else they did not form discrete encapsulated bodies, but were represented by smaller masses of adrenal tissue scattered among the very abundant perirenal

fat. This latter supposition, however, has not been tested by histological study of the material in question. Scattering of the adrenal tissue is not unknown, however, among primates (vide infra). I likewise am unable to give any information regarding the adrenal glands in the juvenile orang, for no attention was devoted to these structures at the time the dissection was made. In the newborn orang, however, the adrenals are present as definite and relatively quite large structures, essentially triangular or wedge-shaped in form. They closely cap the kidneys, lying just medial of the upper pole. Each weighs 1 gram. Adrenal weight thus is to kidney weight as 0.20 is to 1. The adrenal therefore appears to be relatively somewhat smaller (to kidney) in the newborn orang than it is in newborn man (*e.g.*, cf. De Jesus, De Leon et al., 1933). The adrenals, as is well known, undergo an ontogenetic reduction (to kidneys) in man. The same growth change is found in the chacma baboon (Anthony and Villemin, 1923). In all likelihood, therefore, such a developmental process occurs in the orang-utan. If such an assumption is warranted, then the available data suggest that at the time of birth the reductive process is more advanced in the orang than in man.

According to Mayer, the adrenal glands of his female orang were small. Anthony, on the other hand, found these organs to be proportionally larger in his female orang than in man; each adrenal was shaped like an inverted L, and lay capping the pole of the kidney and extending downward along the medial border of the latter structure.

B. Other Primates.—In lemurs (*Lemur variegatus*, *Galago* sp., *Nycticebus* sp., *Perodicticus potto*), I find that the adrenal glands do not cap the upper poles of the kidneys, but are far removed in a cranial direction. Among both New World and Old World monkeys, the adrenals either cap the kidneys directly or else approach them closely in all specimens that I have examined. This close association of adrenal and kidney is normal for man, and probably for the anthropoid apes as well.

The adrenals of *Tarsius saltator* are very elongated, somewhat triangular and relatively large in comparison with the kidneys. In *Lemur* they are triangular or wedge-shaped, in *Galago* ovoid, in *Perodicticus* very flat and triangular in section, while in *Nycticebus* they are relatively smaller than in the preceding, are flattened and ovoid in section, and exhibit curious little fat-like appendages along their borders. *Ateles geoffroyi* possesses adrenals that are definitely ovoid in cross-section, but in other New World forms (*Callithrix jacchus*, *Saimiri sciureus*, *Cebus variegatus*) they are triangular in cross-section as they are in man, and are relatively larger than in lemurs. In all Old World monkeys and apes that I have studied, these organs regularly are triangular in cross-section.

Accessory adrenals, which are well-known to occur in man, have been noted by me in *Erythrocebus patas* and *Perodicticus potto*.

Summary and Conclusions

Any attempt to indicate the phylogenetic position of the orang-utan from the structure of its thoracic and abdominal viscera can only be made by a comparison with all of the other primates. Hence a condensed survey of the entire order is desirable. The conditions of the viscera in the several groups of primates are summarized in the following table, so that further detailed discussion is unnecessary.

The four anthropoid apes and man possess in common a number of visceral characters that clearly pronounce their affinities, namely: The high and rather transverse disposition of the heart; the marked tendency to reduce the gross lobation of the lungs; the restriction of the pleural sacs and their sternal dissociation; the formation of a true vermiform appendix, both grossly and histologically; the development of a sigmoid colon; the completion of an ascending mesocolon; the marked inclination toward fixation of the large intestine; the development of a secondary jejuno-ileal mesentery; and—except in the gorilla—the marked reduction of hepatic lobation. These all are characters that are essentially peculiar to man and the apes, and in combination offer another strong

	Lemurs	Tarsiers	New World Monkeys	Old World Monkeys	Anthropoid Apes and Man
Heart	1. Long axis in cranio-caudal direction, so that cardiac apex is low.	1. Essentially as in lemurs.	1. Essentially as in lemurs.	1. Much as in lemurs.	1. Long axis forms greater angle with that of trunk, so that cardiac apex is higher.
	2. Two arteries from aortic arch.	2. Three arteries from aortic arch.	2. Two or three arteries from aortic arch.	2. Usually two arteries from aortic arch.	2. Usually two arteries from aortic arch in gibbon and orang, three in chimpanzee, gorilla and man.
Thymus	?	Two lobes. Persists even in adult?	?	Three lobes (in *Macaca* and *Papio*).	Two lobes in man, chimpanzee and orang, three in gibbon and gorilla.
Trachea	Cartilages sometimes complete dorsally.	Cartilages usually incomplete dorsally.	Cartilages incomplete dorsally.	Cartilages incomplete dorsally.	Cartilages incomplete dorsally.
Lungs	Lobar formula usually L 3, R 4.	L 3 to 5, R 5 or 6.	L 2 or 3, R 4.	L 2 or 3, R 4.	L 2, R 4 in gibbon; L 2, R 3 in man, gorilla and chimpanzee; normally no gross lobation in orang.
Pleura	1. Sternal reflections close together.	?	?	1. Sternal reflections close together.	1. Separation of sternal reflections.
	2. Vertebral reflections low.	2. Vertebral reflections low.	2. Vertebral reflections low.	2. Vertebral reflections higher than in lemurs.	2. Vertebral reflections higher than in Old World monkeys.

	Lemurs	Tarsiers	New World Monkeys	Old World Monkeys	Anthropoid Apes and Man
Stomach	Usually globular. Left portion very large.	As in lemurs.	Left portion often large. Stomach elongated in some forms.	Lasiopyginæ: Left portion generally not very marked. Colobinæ: Stomach highly sacculated and complex.	Tendency toward elongation. Left portion smaller than in lemurs.
Duodenum	Not clearly demarcated grossly.	As in lemurs.	Better indicated than in lemurs and tarsiers, with beginnings of annular form.	Well demarcated, and tends to assume annular form.	Even more distinctly demarcated than in monkeys, and tends to assume more complete annular form, especially in man.
Jejuno-ileum	Free complex coils.	Free complex coils.	Free complex coils.	Free complex coils.	Free complex coils.
Cæcum	1. Long in most forms.	1. Shorter than in most lemurs.	1. Shorter than in tarsiers.	1. Very short.	1. Very short.
	2. Rudimentary appendix in some Lorisinæ only.	2. No appendix.	2. No appendix.	2. No appendix.	2. True appendix present
	3. Ileo-cæcal junction not complex.	3. Very simple ileo-cæcal junction.	3. Ileo-cæcal junction much as in lemurs.	3. Simple ileo-cæcal junction.	3. Formation of definite ileo-cæcal valve.
Colon	1. Long in many forms, especially in Lorisinæ.	1. Very short.	1. Long in some Callitrichidæ, very short in Cebidæ.	1. Longer than in Cebidæ.	1. Shorter than in Old World monkeys, but longer than in Cebidæ.

	Lemurs	Tarsiers	New World Monkeys	Old World Monkeys	Anthropoid Apes and Man
	2. Tendency of proximal portion to form complex loop or coil, reaching extreme in Indrisinæ.	2. Extremely simple. No ascending portion. Transverse portion not always defined.	2. Ascending, transverse and descending parts differentiated.	2. Ascending, transverse and descending parts differentiated. Beginnings of a sigmoid flexure.	2. Ascending, transverse and descending parts differentiated. Definite sigmoid *flexure* except in some gibbons.
	3. Occurrence and development of teniæ variable.	3. No teniæ.	3. Usually three teniæ.	3. *Three teniæ.*	3. Three teniæ
Peritoneum	Complete dorsal mesintestinum. Mesoduodenum extensive. Common mesentery for jejuno-ileum and first part of colon.	Complete *dorsal mes*-intestinum as in lemurs.	Mesoduodenum shortened or obliterated. Complete dorsal mesintestinum for rest of bowel. Common mesentery for jejuno-ileum and ascending colon still present.	Mesoduodenum regularly obliterated. Complete dorsal mesintestinum for rest of bowel. Beginnings of a separate ascending mesocolon.	Mesoduodenum obliterated. Secondary mesentery for jejuno-ileum developed. Completion of separate ascending mesocolon. Increasing tendency toward retroperitoneal fixation of ascending and descending parts of colon. More complete fusion of greater omentum with transverse colon than in other primates.

	Lemurs	Tarsiers	New World Monkeys	Old World Monkeys	Anthropoid Apes and Man
Liver	Four major lobes, with left lateral largest. Caudate lobule very prominent. Minor lobulation common. Gall-bladder exposed ventrally. Inferior vena cava pierces liver. No bare area.	Four major lobes, with left lateral largest, but lobation less marked than in lemurs. Caudate lobule small. Gall-bladder unexposed ventrally.	Four major lobes, but left lateral shows tendency toward reduction. Caudate lobule well-developed. Minor lobulation common. Gall-bladder unexposed ventrally. Vena cava pierces liver. Usually no bare area.	Lasiopyginæ: Four major lobes, with further diminution of left lateral. Caudate lobule reduced. Minor lobulation common. Gall-bladder unexposed ventrally. Vena cava pierces liver. Beginnings of a bare area. Colobinæ: highly lobulated and greatly altered.	Three major lobes in man, orang, chimpanzee and gibbon; four in gorilla. Further reduction of caudate lobule, especially in man and gibbon. Minor lobulation uncommon. Gall-bladder unexposed ventrally. Vena cava usually pierces liver except in man and gibbon. Bare area well-developed.
Pancreas	May be divided into two distinct parts.	Divided into two distinct parts.	Undivided.	Undivided.	Undivided.
Spleen	Long and narrow. May be highly curved.	Long, narrow, and curved.	Long and narrow.	Shorter and broader than in New World monkeys.	Variable in form, but usually less elongate than in Old World monkeys.
Kidneys	Left more caudal. One medullary pyramid.	Left more caudal. One medullary pyramid.	Left more caudal. One medullary pyramid, except in some specimens of *Ateles*.	Left more caudal. One medullary pyramid.	Right usually more caudal. Many medullary pyramids in man, one pyramid in the apes.
Adrenals	Set apart from kidneys. Of variable form.	Triangular in cross-section.	Lie close to kidneys. Of variable form.	Lie close to kidneys. Triangular in cross-section.	Lie close to kidneys. Triangular in cross-section.

argument for the close genetic affinities of the five animals that comprise this group.

When considering the individual thoracic and abdominal organs, it will be seen that in some instances one member of the group will appear as the most specialized, in other instances yet another member. Thus man is the most advanced with respect to duodenum, cæcum, peritoneum and liver, the orang in regard to lungs and pleura, and the gibbon probably with reference to position of heart and branches of the aortic arch. Conversely, the gibbon is the most primitive regarding the lungs, cæcum, colon and peritoneum, the gibbon and chimpanzee with respect to the pleura, the gorilla in form of liver, and man probably with reference to position of heart and branches of the aortic arch.

Each of the four apes and man exhibits a definite mosaic of visceral characters, some rather primitive, some intermediate, and some highly specialized. There is nothing in this survey to indicate that man possesses any peculiarly close affinities with the chimpanzee, as recently claimed by Weinert (1932), or even with the chimpanzee-gorilla stock a, hypothesis more commonly advanced. It might be claimed, quite as logically, that man is most closely related to the gibbons.

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A STUDY OF SYMMETRY IN THE CENTRECHINOIDEA, BASED ON BEHAVIOR, WITH SPECIAL REFERENCE TO LYTECHINUS VARIEGATUS;[1] INCLUDING A SHORT DISCUSSION OF LINGUISTIC DIFFICULTIES IN DESCRIBING BIOLOGICAL PHENOMENA

RODERICK MACDONALD

THE MATERIAL for this study was collected during June and July, 1934, in the waters known as the Reach, opposite the Bermuda Biological Station. The observations were made sometimes in the laboratory of the Bermuda Biological Station, sometimes in the waters outside.

Lytechinus is the most common of the sea urchins found in the waters of Bermuda. It is gregarious and is found in considerable numbers among rocks (below high tide level), but occurs in greatest abundance on a sandy bottom, usually one fairly well covered with seaweed, and in shallow water (1 to 2 fms.).

Several specimens of *Lytechinus*, watched while in captivity, were observed to move in such a way that they appeared to have a definite axis of locomotion. So consistent was this behaviour that it suggested a locomotor bilateral symmetry in these animals, a condition—so far as is known—not heretofore observed in the regular Echinoidea. It therefore seemed worth while to test this by experiment.

In the first place, the method of locomotion in *Lytechinus* was determined. An animal was placed in a circular glass-bottomed vessel about 12 inches in diameter and 3 inches deep filled with sea water. This was placed on a glass-topped table. The animal's walking movements were then observed from below. The spines used in walking are those on either side of the forward half of the oral surface, except for those in the immediate vicinity of the peristome. During

[1] *See* Clark, H. L. 1933.

walking, these latter spines bend over the mouth and the soft tissues surrounding it. When viewed from below, the walking spines are seen to swing outwards and up and forward, and then down until they come in contact with the surface on which the animal is moving; the spines then move back and thus complete the cycle; in this process, they push the animal forward. In other words, the walking spines on one side of the forward half move clockwise, and those on the other side move counterclockwise.

It was also observed that the spines on either side of interambulacral groove 5, which lies at the forward end of the axis of locomotion, spread apart, forming two rows, one on either side of the axis. The spines in each row take up the circulating movements, corresponding in direction to those of the ambulatory spines on the same side of the locomotor axis. When the animal is walking, the aboral surface slopes downward from the forward end to the hind end.

The tube feet do not seem to take an active part in walking. All the tube feet on the half of the animal that is foremost during walking are extended and move around in an exploratory manner. If one is cut off, all the others are drawn in. After about two minutes they are again extended, most of them appearing at that end of the locomotor axis which in the succeeding walking movements will be the forward end.

In beginning the experiments on *Lytechinus*, a zinc table 6 feet by 2 feet, with 4-inch raised edges, was used. This was kept filled with running salt water, so that when the urchins, half an hour after being collected, were placed on the table they were completely covered with the water, their aboral surfaces being $\frac{1}{2}$ inch to 1 inch below the surface. The long side of the table lay below a southwest window; at no time did direct sunlight fall on any part of the table. Specimens were placed at one end of this table, one for each observation, and as soon as they began to move in a definite forward direction, their anterior ends were marked. Coloured crayon, insoluble in water, was found to be a satisfactory marker. Each animal was observed to keep a straight course until it

came to the obstructing walls of the table, then it either remained at rest for some time or immediately turned its anterior end clockwise or counterclockwise through an angle measuring up to 90 degrees, and then proceeded forward again. In no case did an animal completely reverse its direction of movement under these circumstances; as will be shown later, a more violent type of disturbance was required to cause a reversal. If, while moving in a straight line, an urchin were rotated through 180 degrees, it moved off in the new direction, its anterior end pointing forward as before. In one or two cases an urchin walked the length of the table three or four times in succession (18 to 24 feet) in a straight line, being turned through 180 degrees whenever it reached the obstructing end of the table. After the animals had been on the laboratory table for some time, say two days, it was noted that even without meeting any obstruction they frequently changed their course, the result being that they made a meandering track; but they continued to move with their anterior ends, as marked, pointing forward.

From observations of this kind, made with a large number of specimens, the supposed antero-posterior axis of locomotion was decided upon. This axis is shown as *A* in Fig. 1. Although the animals commonly moved with the *A* + (*i.e.* the anterior) end of the *A* axis pointed forward, some of them occasionally altered their direction of locomotion, proceeding to move either with the *B* + end of the *B* axis or the *C* + end of the *C* axis (see Fig. 1) pointing forward. However, it was noted that after moving forward four or five inches with either *B* + or *C* + directed forward an animal resumed locomotion with the *A* + end of the *A* axis pointing forward. Moreover, the direction of locomotion on the *A* axis tended to remain consistently with *A* + forward. If, when an animal was moving forward, its "anterior" end (*i.e.* the *A* + end of the *A* axis) were moved slowly through any angle up to 180 degrees, it almost invariably moved forward again not only on the same axis but with the anterior (*A* +) end still directed forward. There were a few specimens which, when first put on the table, moved with the *A* − end of the *A* axis

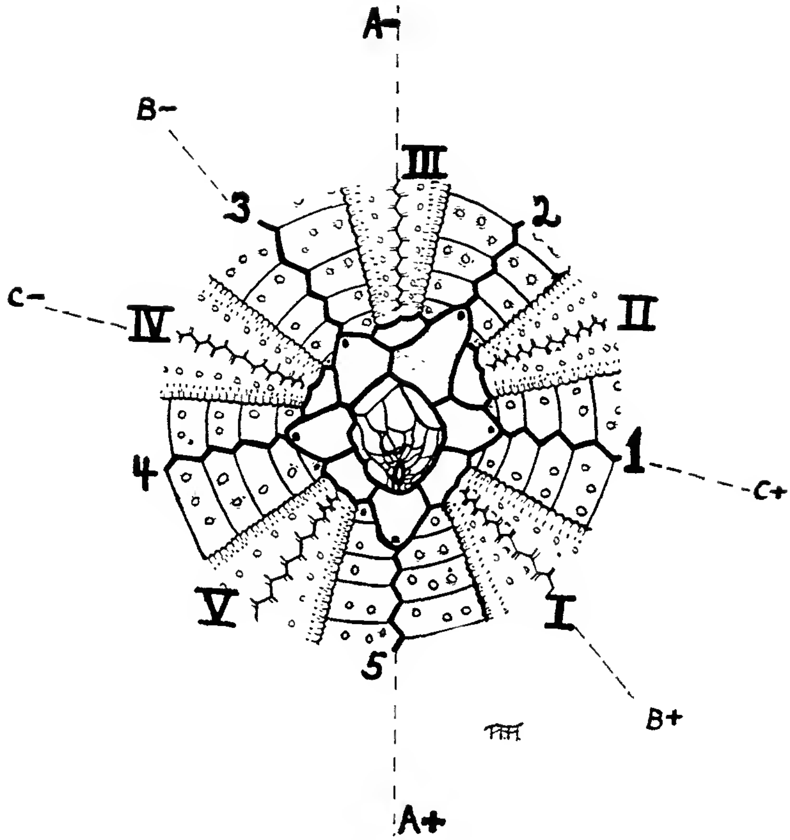

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FIG. 1. Aboral view of a specimen of *Lytechinus variegatus*, with ambulacral and interambulacral areas shown numbered. (See text.)

forward, but their direction of locomotion was more easily reversed than was that of the specimens which started out with the *A* + end of the *A* axis directed forward.

The determination of the anterior and posterior ends of the axis was as follows: it was observed that when an animal moved before being experimented upon, one end of the axis was directed forward much more frequently than the other, and this was therefore called the anterior (*A* +) end. It may be mentioned here as worthy of note that the locomotor anterior end of the axis of *Lytechinus* (*A* +) is the reverse of what is found in the irregular echinoids, where the locomotor anterior is the *A* − end of the *A* axis.

Experiment:

Axis and Direction + = Anterior − = Posterior	Rotations in Horizontal Plane 3 or 4 minutes elapsed between shifts, whether they were voluntary or mechanical	Axis and Direction after Disturbance
$A+$	2 Counterclockwise	$A+$
$A+$	2 Clockwise	$A-$
$A-$	3 Clockwise	$A-$
$A-$	4 Clockwise (and then animal turned its anterior end through 45° in a clockwise direction)	$A-$
$A-$	Animal voluntarily altered to B axis	$B-$
$B-$	2 Counterclockwise	$A-$
$A-$	4 Counterclockwise	$A+$
$A+$	Animal voluntarily altered to C axis	$C+$
$C+$	3 Clockwise	$B+$
$B+$	3 Clockwise	$C+$
$C+$	Animal voluntarily altered axis	$B+$
$B+$	3 Counterclockwise	$B+$
$B+$	4 Counterclockwise	$A-$
$A-$	8 Clockwise	$A-$

From this it is seen that the animal at first, despite being disturbed, maintained the A axis of locomotion. After continued disturbances, it tended to change its direction of locomotion to $B+$, $B-$, or $C+$, and with further disturbances, ceased to move on the A axis. With still further disturbances, it moved once more on the A locomotor axis.

The following tabulation is of an experiment the results of which are interesting but less typical:

Axis and Direction + = Anterior − = Posterior	Rotations in Horizontal Plane 2 to 4 minutes elapsed between shifts	Axis and Direction after Disturbance
$C+$	3 Clockwise	$A+$
$A+$	4 Counterclockwise	$C+$
$C+$	4 Counterclockwise (then animal turned itself through 180°, and then proceeded on same axis)	$A+$
$A+$	Voluntarily turned through 30°	$A+$
$A+$	4 Clockwise	$A+$
$A+$	5 Counterclockwise	$A+$
$A+$	$\frac{1}{2}$ Clockwise (*i.e.* 180°)	$A+$
$A+$	8 Counterclockwise	$A+$
$A+$	$\frac{1}{4}$ Clockwise (*i.e.* 90°)	$A+$
$A+$	6 Clockwise	$A+$
$A+$	1 Clockwise—this rotation was made *vertically* about the A axis	$A+$
$A+$	3 Clockwise and 3 counterclockwise	$A+$
$A+$	14 Clockwise (animal started off on A axis but soon turned about and started off on C axis)	$C+$

In this experiment it is to be seen that, in spite of considerable disturbance, the animal maintained the *A* axis of locomotion until finally, with relatively very great disturbance, it changed to the *C* axis. Few specimens were found which approached this animal in its persistence in maintaining the same axis of locomotion despite mechanical disturbance. In this case it is worthy of note that not only was the axis adhered to the *A* axis, but the direction of locomotion was so persistently *A* +.

These results were checked by observations made in an open pool, using as subject a specimen of *Lytechinus* already living in the pool. The pool used had a surface area of about 120 square feet, and lay between high and low tide marks. A piece of wood 2 feet long and 8 inches wide was laid against the side of the pool to form an inclined plane completely submerged in the water. The board was variously inclined at 15°, 30°, and 45° from the horizontal and the animal placed on the board at each inclination. In every case it moved up the inclined plane in an *A* + direction. It was noted that the urchin used its tube feet and spines to move up this incline.

The animal was now placed on the sand-covered bottom of the pool and its direction of locomotion (*A* +) noted. Next it was placed on the inclined plane, which had been covered with sand, in such a way that *A* + was turned in a direction pointing up the plane. Immediately it traveled up the incline with the direction *A* +. It was noted that the animal at first attempted to use its tube feet to move up the incline, but that not being able to do this on loose sand,[1] it used its spines in a manner similar to that of walking horizontally (see page 88). The urchin, apparently with great effort, slowly walked up the incline from bottom to top (2

[1] As pointed out by Jennings, when discussing walking movements of starfish, . . . "while the suckers are necessary for attachment, the actual locomotion seems to occur rather by the action of the tube feet as levers, in the way described above than as cords for pulling the animal along." Jennings, H. S., "Behavior of the Starfish *Asterias Forreri* De Loriol." *Univ. of California Publications in Zoölogy*, Vol. IV, No. 2, 1907. In the conditions here being considered, not only the lever action of the tube feet but also their ability to attach themselves to the substratum are ineffective in enabling *Lytechinus* to walk up the sand-covered inclined plane.

feet), the supporting spines occasionally slipping, which resulted in the path being zig zag. However, the animal always kept in an $A +$ direction. It was noted that while it was moving upward, the tube feet at the forward end were extended and continually waving from side to side, like so many "feelers." On arriving at the top, the animal was turned around so that the $A +$ end of the axis was pointing down the incline. The urchin did not slide down, but slowly, by means of its spines as before, walked to the bottom of the incline (2 feet), keeping a straight course approximately parallel to the long edge of the board. It was next placed half way up the incline, with its A axis at right angles to the length of the board, and thereupon walked in the $A +$ direction across the board (8 inches), remaining at the edge until it was removed. This was repeated several times, always with the same result. It was noted that when the animal was at rest, all the tube feet were extended and moved from side to side. When the animal was about to walk forward, the tube feet at the anterior end (ambulacra I and V) were stretched horizontally forward, the other tube feet more or less hanging down the side of the animal.

In this experiment, *Lytechinus* shows no signs of geotactic reaction. Furthermore, altering the center of gravity of the animal does not change its axis of locomotion.

When specimens of *Lytechinus* are placed in a glass-sided aquarium, they proceed to climb the walls. It was seen that the specimens studied climbed primarily by using their tube feet, at the same time making efforts to use their spines. On this smooth surface, the spines were not nearly so effective as when used on a rough bottom. The urchins continually slipped as they tried to move upward on their spines. The direction of the slips was carefully noted in the case of a large number of specimens, and the relative positions of the animals about their A axes were marked on the glass walls. The conclusion was that these sea urchins were attempting to walk up the glass wall on the A axis. When an animal reached the surface of the water, it remained just below the surface

indefinitely unless disturbed. In this position of rest, the *A* axis pointed vertically or lay at most 30° to either side of the vertical. If an animal was turned through 180°, it would immediately commence to walk down the wall of the aquarium, apparently making every effort to keep on the *A* axis. Experiments already described show that if sufficiently disturbed, these sea urchins are able to reverse their direction of movement, but in this situation (clinging to the side of an aquarium) they never did so. In short, gravity does not appear to be a strongly disturbing factor in their movements.

When an 8-inch piece of coral rock with overhanging sides (Fig. 2) was placed in the aquarium, completely submerged, it

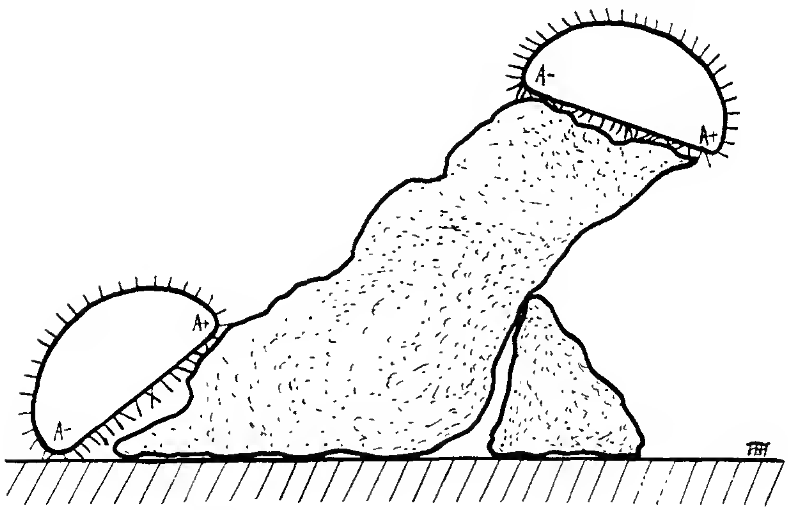

FIG. 2.

was found that some of the sea urchins, instead of walking around it, walked up its side. On reaching the top, they rotated and moved about for an hour or so, apparently making no effort to move down. Ultimately they walked to the edge, released their tube-feet hold, and fell to the bottom. Then a piece of rock with sides the slope of which was not more than 45° (Fig. 3) was placed in the path of the sea urchins. This time not only did some of them climb up, but they promptly walked down the other side.

From these experiments it is concluded that *Lytechinus* shows no signs of geotactic reaction, but climbs the walls of an aquarium or any other obstruction seeking a suitable environment. As will be seen later, there is evidence to show that *Lytechinus* climbs the walls of an aquarium in the course of exploratory journeys for food, or for a substratum on which its food is usually found in its natural environment.

The next experiment made was as follows: A string was placed from one end of the aquarium to the other, below the surface of the water. A sea urchin was placed so that its

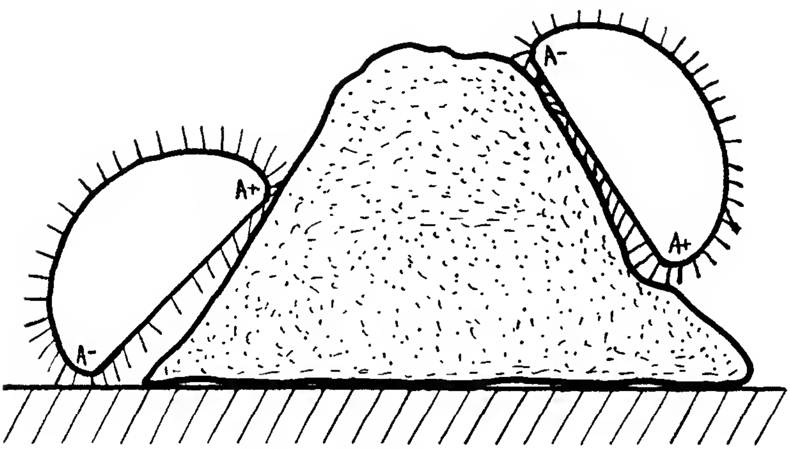

Fig. 3.

oral surface just touched the middle of the length of string. In about 1 minute the animal's tube feet were extended and the string was firmly grasped. The animal hung, aboral side down, for eight hours. Finally it moved along the string by means of its tube feet as far as the end, where it settled on the side of the aquarium. It was once more placed with its oral surface touching the middle of the string, its aboral surface facing downwards. Pieces of shell were presented to it and were immediately grasped by the tube feet. With its aboral surface covered with the pieces of shell, it again moved along the string to the side of the aquarium.

Two specimens were now suspended from the string, some distance apart. They presently approached one another and passed, going to opposite ends of the string.

Next a specimen was suspended from the middle of the string and then another presented, mouth first, to the aboral side of the first individual. The latter could not be made to take hold. A shell was now presented to the aboral surface of the first urchin and was immediately grasped by its tube feet. The second specimen was again presented, mouth first, to the region whereon hung the shell. Immediately it took hold of the shell with its tube feet. A shell was now put on the aboral surface of the second animal and a third specimen attached itself to this. Thus three sea urchins, all of the same size (diam. 3 cm.), were hanging one below the other from the string. After about half an hour, they made efforts to right themselves: the bottom animal walked up over the other two and started to walk along the top of the string, but gravity pulled it over and it moved along suspended by its tube feet, its aboral surface facing downwards. It continued until it reached the side of the aquarium; the second animal followed the same procedure; and finally the first urchin traveled to the end of the string. It is interesting to note that the first animal never loosed its hold on its piece of shell, even when it was supporting the weight of the other two animals. Similarly the second urchin continued to cling to its shell, after the third urchin had grasped it. It is also interesting to observe that in climbing up to the string, the second and third urchins actually took hold of the spines of the other urchins, whereas at first they would not attach themselves to the aboral side of another without a shell between them. (It has been observed throughout these experiments and also in the natural environment of these animals (*Lytechinus*) that only when walking do they pick up debris with their tube feet.)

During this experiment, all specimens moved on their oral surfaces, irrespective of their consequent positional relationship to gravitational pull. In short, it would appear that the impulse to apply their oral sides to a solid surface is what conditions this position to be the normal, rather than a response to gravity; in other words, movements made to regain

this position may be described, in part, as stereotactic, and not geotactic.

Further observations were now made on what might be called the righting movements of a number of specimens. Each animal, while under water on the laboratory table, was turned over and made to rest on its aboral surface; whereupon all the spines became active and perpendicular to its surface. Presently the tube feet in the region of the *A* + end of the locomotor axis, *i.e.* in ambulacra I and V, became active and fully extended. They attached themselves to the solid substratum and gradually pulled the body of the animal over until the *A* axis was perpendicular to the table. During this process, as soon as the tube feet nearer the mouth were brought close enough to the table, they also attached themselves to its surface and helped to pull the animal in the same direction. Once the animal had attained the vertical position, *i.e.* once its *A* axis was vertical, the spines on the rows of plates in interambulacra 3 and 2 on the periphery of the aboral side were directed away from the *A* axis and began to rotate. The rotation of these spines was similar to what was found when the animal was walking in a horizontal path, the spines, when the animal was viewed from the aboral side, in interambulacrum 3 moving clockwise and those in interambulacrum 2 moving counterclockwise. This interesting piece of behaviour seemed to aid the action of the tube feet in bringing the body of the animal far enough beyond the vertical position to enable gravity to pull it over to its natural position—that is, with its oral surface on the bottom. In other words, when an animal is laid on what is normally its "dorsal" surface, it assumes its natural position by making a back somersault over its anterior end. A very large number of animals were tested, and in every case the method of righting was the same, the axis about which they turned in regaining their normal position being at right angles to the *A* axis. The time taken to do this varied from 5 to 10 minutes.

It is important to note that not only is the righting movement as restricted as locomotion, but also that in every case

studied, and repeatedly with the same animal, the righting movement was made about the anterior end (A +) of the locomotor axis.

In order to find out what effect, if any, light had in the movements of *Lytechinus*, an aquarium 2 feet by 1 foot, 1 foot deep, was fitted out with a wooden bottom and a glass window 4 inches square at floor level at one end of the tank. By otherwise making the aquarium light-tight, a beam of sunlight coming in through the window was obtained. The aquarium was filled with circulating sea water and a specimen placed at the far end from the window. Immediately, and traveling almost three times as quickly (about 9 inches per minute) as on the shallow table used in earlier experiments, the animal made a straight path, with A + forward, to the window. It then climbed up the window and remained there, fastened by the tube feet on its oral surface, although there was no mechanical obstacle to prevent it from climbing to the top of that wall of the aquarium. It was noted that in no case did the animal climb up the sides of the aquarium apart from this making for the small window. Several animals were used, with the same results. In aquaria similar in size to that described above, with four glass walls, situated in diffuse daylight or in direct sunlight, and no matter what the condition of aeration, the animals always climbed up the sides of the aquarium. If this had a sand bottom and was set out in the open in the sunlight, the urchins remained on the bottom. It may be that the photosensitive zone of the animal is in the region of the mouth, since in directional sunlight in the otherwise darkened aquarium, *Lytechinus* not only walked to the window but also tilted itself until its mouth was pressed against the glass, where it remained. In the lighted aquarium, with a sand bottom, the light was reflected up around the mouth of the animal and was perhaps sufficiently intense to stimulate the photosensitive region and thus keep the animal on the bottom. This matter will be discussed later, the important point to notice here being that the loco-

motor axis of *Lytechinus* when moving in response to a light stimulus was the *A* axis and the direction was *A* +.

Four specimens of *Lytechinus* were now placed in a glass-walled aquarium of the same dimensions as that used previously, and with the floor made of wood; this was put in the open, with one glass side facing south. The aquarium was filled with circulating salt water. At 5.30 p.m. the sky was cloudless, and the urchins were climbing up the glass sides of the aquarium toward the sun. Sand from the beach was now placed on the bottom of the aquarium, and in half an hour the urchins had come down from the sides and were resting on the sandy bottom. The sand was next cleared from half of the bottom and the aquarium placed so that both halves of the bottom were equally lighted by the sun. Two specimens were put on each half. After three quarters of an hour, the two on the bare wood were climbing the glass side, while the two on the sandy half of the bottom were still there and making no attempt to climb.

In these experiments it was noted that the light of the sun was so intense that it apparently overshot stimulation value and actually resulted in the urchins moving into the shade, whereas the light from a cloudy sky or diffused light was such that the urchin's phototactic threshold value was undershot and the animal appeared neither negatively nor positively phototactic. The earlier experiments were conducted under the latter condition.

Six specimens of *Lytechinus* were now placed in the aquarium, the bottom being covered with ground coral rock such as is used in Bermuda for building purposes. This was devoid of any organic matter. The aquarium was put out in the open and exposed to sunlight and kept filled with circulating sea water. The animals remained on the bottom for 6 days and at about this time showed signs of weakness. When disturbed they would barely respond, moving very slowly. They were found climbing the glass sides of the tank with what appeared to be great effort, and were dropping the

debris—shells, pieces of coral, and algæ—commonly found held on their aboral surfaces by their tube feet (pp. 95, 96).

Two dead fish were now put in the aquarium and the sea urchins were taken from the walls and placed on the fish. Immediately they attached themselves to the fish by their tube feet. After some time (24 hours), one urchin was seen to be clinging to the end of the tank, at the same time holding onto the tail of one of the fish, which being filled with air was tending to pull both its own carcass and the sea urchin to the surface. Pushed off the wall of the aquarium, the urchin dropped to the bottom, still holding the fish's tail. The buoyancy of the fish kept the urchin in a tilted position. This, together with the fact that it was unable to attach its tube feet to the bottom of the tank covered with the ground coral, and the fact that it could not get enough of its tube feet on the fish to pull the latter down to a favorable position, resulted in the observation that in about two minutes the urchin was forced to release its hold and the fish floated to the surface. After ten days, it was found that the urchins were all walking on the bottom and apparently were again strong and vigorous, as indicated by their active response to mechanical disturbance and also by the fact that their aboral surfaces were covered with debris. It was noticed that two of them had pieces of the bones of the dead fish on their aboral surfaces, the flesh of the fish having entirely disappeared. This had not all been eaten by the urchins, but some of it had disintegrated and mixed with the sand, which the urchins were now eating. From this experiment it is learned that if the bottom of the tank is covered with sand, the animals remain on the bottom for several days. This is in striking contrast to what happens if the same animals are put in a tank with a bare wooden bottom. In this case they immediately walk up the walls of the tank. If, however, no food is in the sand, the animals will ultimately climb the walls. When food is placed in the sand, they will remain on the bottom, making no effort to climb.

A common habit of *Lytechinus*, which it shares with some other sea urchins, notably *Strongylocentrotus dröbachiensis*,

is to cover its aboral surface with debris; this it does by means of its tube feet. It was considered worth while to find out if possible what might be the interpretation of this behaviour, if any. When healthy specimens of *Lytechinus* which have been freed from debris on their aboral surface are placed in their natural environment or in a salt water aquarium, they immediately set about covering their aboral surfaces with any debris which may be around. In their natural environment they cover themselves with pieces of coral, shell, and algæ. In the aquarium, they have frequently picked up in this way pieces of glass tubing and pebbles. It has been observed throughout these experiments and also in the natural environment of these animals, that only when walking does *Lytechinus* pick up debris with its tube feet and place it on its aboral surface. It is true that covering itself with debris is a fairly successful method of hiding the animal from human observation, but whether or not this is the case so far as the sensory equipment of possible enemies is concerned, no evidence is available to say. The covering activity seems to be incidental to normal walking activities.

Several experiments were made in an endeavor to learn something about the nervous control of locomotion. Oxalic acid crystals were placed on the anterior end of the A axis of several specimens in the aquarium. After a few seconds they all traveled rapidly with the posterior ends (A −) of their axes pointing forward. Similarly, when oxalic acid was placed on the A − end of the axis, the animals traveled equally rapidly with the A + end forward. When, however, the acid was placed on one side of the axis, the animal merely rotated about the axis perpendicular to the A axis away from the source of irritation, remaining in one place.

A cut was now made across the A axis in the soft tissue about the mouth of one specimen, so as to cut the base of the radial nerves running along ambulacra I and V. Oxalic acid was placed on the animal's test at the A − end of the A axis. The animal immediately moved along the A axis in the A + direction, apparently in an endeavor to escape from the irritation of the acid. The cut and the placement

of the acid were then reversed in relation to the *A* axis. The result was as before, that the walking movements performed ordinarily by the walking spines along the sides of the animal were unhindered by any loss of nervous coördination.

In the third of this group of experiments, the cut was made on one side of the *A* axis, that is, cutting the base of the radial nerves along ambulacra II, IV, V and I thus cutting off all possible nerve supply to one physiological half of the animal. Oxalic acid was placed over the *A* – end of the locomotor axis, and instead of the animal's walking away from the source of irritation, the walking spines on the side of the *A* axis opposite the cut carried out normal walking movements, while the walking spines on the side of the cut moved in such a way that no real walking movements were possible. As a result of this non-coördination on the part of the walking spines on the cut side of the axis, the animal rotated approximately about its center, remaining in one place. It was thus found that by injuring the center of either of these physiological halves of the nervous system of a number of specimens of *Lytechinus*, a lack of coördination of walking movements resulted on the injured side. If, however, the cut was made across either of the ends of the *A* axis, which separates the physiological halves of the animal, or even across both these ends in the same animal, no lack of coördination of walking movements was observed. It is thus seen that the walking spines and their nervous control are bilaterally symmetrical about the *A* axis.

In the light of these experiments it would appear that *Lytechinus* is functionally bilaterally symmetrical about a definite axis. Viewed aborally, this axis lies immediately to the left of the madreporite, passing through the neighboring ocular plate III and the diagonally opposite genital plate 5 (Fig. 1). According to Cole (1913), in *Asterias forbesi*, the physiological anterior as he determined it lies in this same position. In the irregular Echinoidea—spatangoids and clypeastroids—it has been shown by Parker (1927), in *Echinarachnius parma*, and by Crozier (1920) in *Mellita sexies-*

perforatus, that the axis of locomotion corresponds with the structural axis of bilateral symmetry. In the spatangoids, the author has observed the same coincidence in these axes in *Echinocardium cordatum*.

The matter of orientation in the Echinoidea was first given serious attention by Agassiz (1836), later by Lovén (1874), and more recently by Jackson (1912), Ubisch (1913), and Gordon (1926). Lovén discovered an arrangement based on the size and character of the primordial ambulacral plates in the peristomial border of irregular Echinoidea and often in the regular Echinoidea whereby one can locate the antero-posterior axis of these echinoderms. According to the findings of these investigations, this arrangement of primordial ambulacral plates is a genetic structure and does not change later in development except in the regular Echinoidea, where the arrangement disappears in the adult. The only adult member of the regular Echinoidea in which it exists, as far as is known, is the ancient *Bothriocidaris archaica* (Jackson), found in the Ordovician. Accordingly, in the great majority of regular Echinoidea the above law of Lovén does not help in orientating these animals. As a result of Jackson's investigation, a dependable method of orientating regular Echinoidea, including adult forms, has been established. He found that during the development of the regular Echinoidea the ocular plates enter the periproct in such a sequence as to emphasize the bilateral symmetry of these Echinoidea through a definite axis, namely III, 5 (Fig. 1). This axis agrees with the axis found by Lovén, and also with the axis about which the irregular Echinoidea develop their patent bilateral symmetry. Finally, this axis coincides with the *A* axis, or locomotor axis, in the investigations described herein.

As has been seen, *Lytechinus* can move in both directions on the locomotor axis. An anterior and posterior end are thus functionally not established, as in *Mellita*, and *Echinacharincus*, for example, and probably in most irregular Echinoidea. According to our observations, *Lytechinus* moves most commonly with the so-called structurally pos-

terior ($A +$) end of the axis (Fig. 1) carried forward, and this has thus been termed the anterior end throughout the experiments.

In *Lytechinus* the anus is eccentric, lying near to the border of the periproct in the region of interambulacrum 5 and either on the III, 5 axis or—less frequently—on the I, 3 axis. On examination the periproct of *Lytechinus* is seen to be covered by a large number of plates, these being smallest and most numerous near the anus. The relative plasticity of the various parts of the periproct is correlated with the size and number of plates borne on these parts. When defecation takes place, the rectum is extruded and as a result of the relative size and arrangement of plates on the periproct and the consequent plasticity of the latter, the anus is carried above the level of the periproct border and is directed towards and above interambulacral groove 5, beyond the border of the periproct, thus facilitating the removal of the fecal pellets from the body of the animal. Accordingly, the anus, whether or not it is on the III, 5 axis when defecation is not taking place, is always there during this process.

When the animal is moving with ambulacrum III directed forward and is about to defecate, the body, which during walking in this direction is tilted so that the aboral surface slopes downward from III to 5, is still further tilted in this direction; owing to the position of the anus as described above, and to the force of gravity, the fecal pellets, which are somewhat spherical in shape, roll down interambulacral groove 5.

When *Lytechinus* is moving with interambulacrum 5 carried forward and is about to defecate, it moves more slowly and the aboral surface, which when the animal is walking always slopes downward from the forward end, takes up a more or less horizontal position. The anus is directed over interambulacral groove 5, and the removal of the fecal pellets in this case is assisted by the neighboring spines, which by their rotation cause the pellets to roll down interambulacral groove 5 and sometimes down ambulacral groove I.

If defecation is about to take place when the animal is at rest, the body assumes the position taken when the animal walks with ambulacrum III directed forward. As has been pointed out, when the animal is walking, the aboral surface of *Lytechinus* slopes downward from the end carried forward. Should this end be ambulacrum III, then the getting rid of the fecal material from the surface of the body is mechanically speaking a simple matter. If the forward end is interambulacrum 5, defecation tends to inhibit further walking in this direction, and the removal of fecal pellets is accomplished with greater effort. Enormous quantities of material (sand with organic matter) are almost constantly being passed through the alimentary tract, so that the getting rid of fecal material is an ever-present problem to the animal. Since the fecal pellets are more easily removed during defecation when *Lytechinus* is walking with ambulacral groove III carried forward than when interambulacral groove 5 is carried forward, and also since in the latter case forward movement is arrested during defecation, it might be expected that in the course of time *Lytechinus* will cease to walk with interambulacral groove 5 directed forward, which is the case in the irregular Echinoidea. Our observations show that there is no indication of elimination of locomotion with interambulacral groove 5 directed forward. On the contrary, this direction of locomotion is so common that in the above-described experiments interambulacral groove 5 has been designated the anterior of the axis of locomotion (A +). That this is the functional anterior is further supported by the fact that during righting movements *Lytechinus* rotates vertically about genital plate 5, with characteristic movements of the spines in that region. In addition, the anus lies toward genital plate 5; and also in the course of development the ocular plates which first travel in to the periproct and become *insert* are those on either side of genital plate 5. These functional, structural, and developmental specializations indicate the importance of this region and suggest that the true anterior of *Lytechinus*—at least as the locus of activities

which are generally associated with the anterior of an animal—lies in this region.

It is commonly stated that sedentary animals tend to be radially symmetrical, and actively moving animals bilaterally symmetrical. The echinoderms in general have a superficial radial symmetry and show great variation in their sedentary habit. This ranges from the permanently attached adult crinoids to the actively moving ophiuroids. Both of these are radially symmetrical and according to what has been said with regard to actively moving animals, it would be expected that the ophiuroids would show signs of bilateral symmetry. It is to be noted, however, that it is the high specialization of all the arms with their articular surfaces and processes for the attachment of muscles and their consequent independent mobility that has made for the active movements of these animals. Furthermore, those appendages are well marked off from the disc, or main body of the animal, and their independence of movement is thus further enhanced. So far, there is no evidence of circumscribed directional movement in ophiuroids. In the asteroids the arms are not so highly specialized and are not marked off from the main body of the animal as in ophiuroids. It might be said that here is indicated a centralization of the locomotor mechanism. It is interesting to note that there is some evidence of circumscribed directional movement in asteroids. In the Echinoidea the arms are completely fused to the body, indicating a further centralization of the locomotor mechanism, which would make for a greater possibility of directional movement than in the ophiuroids or the asteroids. Among the Echinoidea there is a great variation in locomotor activities. The cidarids are extremely sluggish but do move. The centrechinoids are somewhat more active. Here, however, there is a difference between those living habitually on rocks and those living on hard flat sandy or pebbly bottoms, the latter being more active. Finally, the irregular echinoids, which are among the most active of all the Echinoidea, have a well marked structural bilateral symmetry, with which

is correlated their habit of burrowing and walking with circumscribed directional movements in the sand.[1]

Lytechinus is among the most active of the regular echinoids. Although it is found on rocks, it occurs in large numbers on a fairly hard sandy bottom, where it may walk as many as five feet in one direction, taking half an hour to travel that distance. It is suggested that the environmental conditions, namely stretches of sandy bottom, the relative uniformity of light intensity over a wide area, and the habit of feeding on the detritus-containing sand, all tend to make explicit the functional bilateral symmetry implicit in the animal at least so far as locomotion is concerned. This gradual reëstablishment of functional bilateral symmetry in *Lytechinus* is associated with a more clearly defined structural bilateral symmetry, evidence of which is seen in the displacement of the anus along the *A* axis. It may be that here in *Lytechinus* we have a condition which foreshadows or prefigures the conditions found in the irregular echinoids.

Ubisch (1913) was the first to demonstrate the importance of the II, 4 axis (Fig. 1) in the symmetry of Echinoidea. He found that the calcareous skeleton of the imagines of regular and irregular echinoids are bilaterally symmetrical about this axis, which he called the primordial axis of symmetry. He also stated that later in development both regular and irregular echinoids become radially symmetrical, the regular echinoids remaining so and the irregular echinoids becoming secondarily bilaterally symmetrical. This new axis of bilateral symmetry (Lovén's axis) does not coincide with the primordial axis of symmetry. Gordon (1928), working along similar lines to Ubisch, agrees in general with his findings, making particular mention of the importance of the II, 4 axis of bilateral symmetry in the imagines of both regular and irregular echinoids; but unlike Ubisch she qualifies her statement on the radial symmetry of these forms. "In spite of its shape, the test of the imago of a regular urchin is almost

[1] Dr. H. L. Clarke has told the author that he saw a specimen of *Lovenia elongata* at Broome, West Australia, travel on the sandy shore towards the receding tide at the rate of 1.5 feet per minute.

bilaterally symmetrical about the primordial plane of symmetry. This is more pronounced in the imago of a primitive form like *Arbacia* than in that of *Echinus* or *Strongylocentrotus* . . . . As the young urchin increases in size, the bilateral symmetry becomes less and less apparent, although still present, and the adult seems to be radially symmetrical" (p. 314). "Strictly speaking, a regular sea-urchin is neither radially nor bilaterally symmetrical. The skeletal anatomy is most nearly symmetrical about the primordial plane. Lovén's Law, though not always strictly adhered to (especially as regards arrangement of interambulacral plates), is important" (p. 315).

As already remarked, Lovén has shown that the size and arrangement of the primordial ambulacral plates adhere to Lovén's axis. He also maintained that the interambulacral plates at the base of the corona adhere to this axis. This latter statement, as pointed out by Jackson, though often true is frequently not true. However, it would appear that there is a striking tendency to dominance of Lovén's axis at this stage of development. During the development of the corona, not only the ambulacral plates but also the interambulacral plates originate in direct contact with the ocular plates, and it would appear that during further growth of the skeleton of regular sea urchins the interambulacra, which Jackson (page 62) says function chiefly as space fillers, are influenced in their growth and development by the ambulacral plates. In this connection, Deutler (1926) says: "Man hat den Eindruck dass diese Ambulacralplatten sind, welche das eigenartige Wachstum der Schale bestimmen, dass das Wachstum der Interambulacral sich nach den von den Ambulacralplatten geschaffenen Verhältnissen richtet, also ein Regulations wachstum ist. Dass das Wachstum der Ambulacralplatten über das der Interambulacralplatten entscheidet, halten wir deshalb für wahrscheinlich, weil es praktisch ist, dass zuerst die Ambulacralplatten maximal wachsen, und dass diese dann, nachdem sie ihre maximale Grösse in der Schale erreicht haben, bis zum Peristomrand

möglichst breit bleiben; denn dadurch wird sehr früh für die Füsschen kanäle Platz geschafft, dadurch werden die beiden Füsschenreihen des Ambulacrums auseinander geschoben, und dadurch bleiben diese selbst noch am Peristomrand in zeimlich weiter Entfernung von einander. Das wachsende Ambulacralgefässystem könnte den Anstoss zu dem eigenartigen Wachstum der Schalenplatten geben. Den Beweis dafür müssen wir allerdings schuldig bleiben" (p. 153).

The fact that during growth the structure of the corona is constantly subject to change is commented on by Lovén (1892) as follows: "In all Echinoidea the growth of the corona is effected by new plates being successively added at the aboral termination of the ambulacra and interradia and by their increasing in size and solidity. As long as the animal lives, there is at work, more or less, in every part of its frame a continuous movement of reabsorption and renewal, of taking on one form and losing it for another . . . and this process is perhaps nowhere more conspicuous than in the corona of the Cidaridæ and Echinidæ."

Further evidence of the plasticity of the skeleton, at least in the early adult life of the individual in regular sea urchins is shown by Jackson's findings on the migration of the ocular plates to the border of the periproct. The sequence with which these plates migrate adheres to Lovén's axis. It is true that the water vascular system and the internal anatomy generally of sea urchins are not bilaterally symmetrical, but it is worthy of note that the madreporite lies almost midway between the primordial and Lovén's planes of symmetry. The position of the madreporite may be the result of the relative effectiveness of the dominance of an inherent bilateral symmetry of the animal and that of the organization of the internal organs, more particularly the water vascular system on the plastic skeleton. With regard to the corona, the manifestation of bilateral symmetry is inhibited by the water vascular system, which as Deutler suggests, imposes its organization on the constantly changing form, and consequent impressionability of the corona.

The tendency for Lovén's axis to dominate the organization of the regular sea urchins is supported by our observations in the case of *Lytechinus*, where the locomotor axis coincides with Lovén's axis. We have also made observations on the movements of *Eucidaris tribuloides*, *Tripneustes esculentus*, *Arbacia punctulata*, *Echinometra lacunter*, and *Strongylocentrotus dröbachiensis*. The first three are primitive forms and show no evidence of a functional axis of bilateral symmetry. *Echinometra* is elliptical through the I, 3 axis, but from observations on its walking and righting movements, it is definitely functionally bilaterally symmetrical about Lovén's axis. This is remarkable, considering the shape of the animal, and indicates how very dominant, functionally, is Lovén's axis in this highly specialized sea urchin. Investigations on the movements of *Strongylocentrotus*, at present in progress, indicate that the functional axis may be Lovén's axis or the primordial axis. More observations are necessary before it can be said which, if any, of these axes is adhered to most commonly. Still it does appear that *Strongylocentrotus* is in its walking and righting movements bilaterally symmetrical about these two important axes.

While writing this account of observations on the above sea urchins, the author came across a paper written by Katsuzo Onoda (1933). Onoda noticed while examining the denuded tests of *Heliocidaris crassispina* that the tubercles of nearly one half of the hemisphere of the test were considerably smaller than those of the other half, and that in undenuded specimens the spines of nearly one half of the hemisphere were very much shorter and thinner than those of the other half. In Clark's (1925) description of this sea urchin, he states that the spines are slender despite the name. Onoda's observations apparently account for the discrepancy indicated by the name *crassispina* and Clark's description. This sea urchin is highly specialized, comparable in this respect to *Echinometra*. Onoda concludes as follows: "Thus it is clear that there is a rather definite physiological differentiation in the ambitus of this regular sea-urchin . . . it is

of some interest that the physiological antero-posterior axis of the present species coincides exactly with that in Spatangoids." It is of special interest to note that Onoda found that during locomotion the *A*—end of the *A* axis (*i.e.* the region with small spines) was consistently directed forward, directional movement thus strictly coinciding with what we find in the Spatangoids.

Conclusion

The evidence so far brought forward seems to show that a bilaterally symmetrical organization is the inheritance of all the members of the Echinoidea. This may be expressed both structurally and functionally. The structural expression is portrayed in the sea urchin during development; the variation in this portrayal, namely a different axis of bilateral symmetry in each of the following stages—the free swimming larva, the imago, and the adult—is inherent in the animal and would appear to be in its genesis independent of the external environment. The functional expression, on the other hand, is in its manifestation to a great extent dependent on the external environment, together with the needs of the animal as a whole. Granted that the conditions are favorable to functional expression, this may become explicit, as it does in *Lytechinus*, and gradually conform to the form of structural expression already dominant. As a result of this coincidence in structural and functional expression, these tend to become more marked until we reach a stage such as is found in some of the highly specialized irregular Echinoidea, where there is a well defined circumscribed coincident structural and functional axis of bilateral symmetry. There is no evidence that the functional and structural expressions of the organization of sea urchins are exclusively dependent on each other for their manifestation. The point that we wish to make is that in the one case, structural expression, the internal environment is sufficient to make possible the release and limning of that expression; whereas the functional expression requires in addition the external environment for its manifestation.

Discussion

The following discussion is written in non-orthodox biological language. The reason for so doing arises from the awareness on the part of the writer that the currently used elementalistic language does not correspond in structure to the observed structure of happenings in nature. Here I accept the linguistic and semantic revision of Count Alfred Korzybski, as formulated in his book *Science and Sanity, an Introduction to Non-Aristotelian Systems and General Semantics*, and will make use of some of his terminology, such as "order." and "non-elementalism,"—which is a broader conception than "organism-as-a-whole," as it includes by implication the environment, which "organism-as-a-whole" does not. Elementalism in this new sense represents a description of "facts" (objects, functions, relations, etc.) as though the described "elements" or verbal aspects had an independent "reality" in actual life. In addition, elementalism represents a description of objects, functions, relations, etc. as though such issues could be actually isolated. This verbal detachment of linguistic "elements" is artificial. When so described, the object or organism and its functions, etc. become empirically non-existent. These considerations become increasingly important to biologists who realize the confusion brought about by artificial linguistic splittings and linguistic self-deceptions.

Originally biological observations were expressed in anthropomorphic language, and later, through the work of Loeb (1907) and others, this language was replaced by a non-elementalistic language which in its structure corresponded to the observed happenings in nature. This work was of course preliminary and Loeb's followers, although they have worked along similar lines, do not develop in their writings Loeb's important implications, namely that the activities of all living things not only can be expressed in a language equally applicable to sciences other than biology (namely, mathematics, mathematical physics, etc.), but also that the use of such a language is the only way that we can today adequately express the non-elementalistic activities of the organism-as-a-whole. Loeb emphasized the organism-

as-a-whole and to a certain extent applied this new emphasis, and as a partial result the new implications suggested new experiments. One type of reaction was described as "tropism" and another as "Unterschiedsempfindlichkeit" (differential response). These types of reaction, according to Loeb, differ from each other as do the quantities of the dimension of an acceleration from those of a dimension of a velocity. In other words, these two types of reactions belong to different *levels*. The analogy is not strictly true, because in both velocity and acceleration the time factor is present in different forms, whereas in the two types of reactions pointed out by Loeb the time factor emerges in only one. The first type, namely tropism, belongs to the first level, expressed $f(i)$. In the second type, Unterschiedsempfindlichkeit (differential response), which belongs to a second or higher level, a factor emerges—time, and this is expressed $f\frac{di}{dt}$. Hargitt and Jennings argue that the reaction of type $f\frac{di}{dt}$ differing as it does from $f(i)$ contradicts the existence of the latter type. As pointed out by Loeb, this is no more the case than the existence of accelerations contradicts the existence of velocities. The validity of this statement becomes more apparent when we use the non-elementalistic term *order*. The two types of reaction are of different levels. They express different orders of abstractions. Irritability is a dynamic structural characteristic of all protoplasm so far observed. Some reactions on the part of the organism, correlated as they are with the latter's irritability to envirogenic influences, belong either to onel evel—$f(i)$, or to another level $f\frac{di}{dt}$. The identification of these orders, or perhaps the non-recognition that the reactions under consideration belong to two levels or orders of abstractions no doubt led to the semantic [1] confusion of Hargitt and Jennings.

[1] General Semantics is that science which studies the linguistic psycho-biological reactions of human being. In biology the linguistic reaction of the biologist to the activities of the organism must be considered, producing an adequate formulation of what is taking place.

In a recent publication, Foxon (1934) points out the unsatisfactory explanations of tropisms put forward until now, such as Loeb's mechanical hypothesis and Russell's (1934) interpretation of what we see as a "flight response," difficult to reconcile with Clarke's important work on *Daphnia* (1932). Observations of phototaxis in *Porcellana* larvæ made by Spooner (1933) and Foxon (1934) show that this animal moves forward or backward towards the source of light. Foxon has shown that if a Porcellana larva is swimming head forward (*i.e.* normally) toward the source of light and then the light is suddenly moved so that it shines from behind the animals, the larva, instead of reorienting itself to the new source of light, reverses its locomotory mechanism, *i.e.* swims backwards. He also states that "this failure to reorientate is correlated with the possession of the very long spines characteristic of these larvæ for when these spines are cut off, the larvæ, on reversal of the direction of the stimulus, reorientate immediately."

Whereas Loeb's description of what happens is partial and necessarily superficial, based as it is on the visible "machine-like" actions of the organism, Russell's descriptions are anthropomorphic. We agree with Foxon with regard to the inadequacy of Russell's interpretation and should like to draw attention here to the tendency on the part of this author to make anthropomorphic descriptions of the behavior of animals. While describing the reactions of an amœba to stimuli, Russell says: "It is clear also from a consideration of the whole behavior that it is not the stimulus *per se* that is reacted to but its significance," *The Study of Living Things*, 1924 (page 74). Again, "The common element in these stimuli as *perceived* is their significance as indicative of food" (page 77). Here Russell gives to the amœba a standard of evaluation which is that of a human being. The amœba's behavior is based on unrestricted identification. The amœba reacts to a fine needle vibrating close to it in a way similar to that in which it reacts to a moving food organism. The amœba thus identifies the sign with food. Here evaluation is

on a pre-human level. An organism which reacts to the significance of an event has standards of evaluation of a high order and completely eliminates identification in its nervous reactions. Such an organism would be a human being behaving as such. To say, as Russell does, that the significance of stimuli is perceived by the amœba or that the amœba reacts to the significance of a stimulus is anthropomorphic and a false description of what is observed.

Foxon concludes that these movements on the part of Porcellana larvæ are not mechanically produced, as Loeb's theory holds, but that there is some nervous integration going on which determines the manner in which the response is to be produced.

It would appear, in the light of Foxon's significant observations, that the stimulus—light—brings about a dynamic disturbance in the nervous system on the colloidal levels, tending to reorient the dynamic colloido-quantum structure of these cells or their colloido-quantum configurations. This reorientation, however, is obstructed in its visible expression, namely the movement of the animal, as a result of the mechanics of body structure (presence of very long spines, etc.), and results in a reversal of polarity of the dynamic structure of the nervous system and consequent reversal of movement of the animal. When the obstructing mechanics of macroscopic body structure is removed, the reorientation of the dynamic colloido-quantum structure of the nervous system, thus unhindered, expresses itself in the macroscopic reorientation of the body of the animal as-a-whole. This is offered not as an explanation, but as a linguistic expression structurally corresponding to what is observed.

The organism-as-a-whole approach to the study of living things has in its application led Child (1928) to use the term "dynamic or physiological gradients." He pointed out that many of the most important characteristics of living protoplasm are strictly bound up with structural integrity. He also showed that the trafficking between the internal environment and the external environment is dynamically structural

and supplies the energies which activate the organism. Child emphasized the necessary functional inter-relationship of the organism-as-a-whole (non-elementalism, in the Korzybski sense) with the environment, and presented a biological system which could be and was expressed by him in structurally corresponding non-elementalistic terms.

Child's experimental evidence of metabolic gradients has been variously criticized, notably by Parker (1929). As a result of his experiments on flat worms and sea anemones, he found that they "possess a metabolism that in its distribution throughout their bodies is extremely uniform." Yet he states that "This uniformity is replaced by a quantitative diversity only in those animals such as the annelids, the arthropods, the molluscs, and the vertebrates, whose bodies are highly differentiated." Parker does not deny the presence of metabolic gradients, but states that "if present they are not factors in morphogenesis but are at best measures of activity which may serve as features in the description of organisms."

In replying to Parker's criticism Child [1] points out that the criticized theory does not demand a rectilineal ("longitudinal") gradient in the adult of every species and states that "Actually, however, the gradient hypothesis has never implied a fixed metabolic diversity in adult animals."

To the present writer, the importance of Child's work rests not so much on the detailed conclusiveness of his results as on the suggestiveness of his methods in seeking to deal with a possible "measure of activity in the description of organisms" and on his attempt to describe his observations in a language whose structure corresponds to the happenings in the organism as observed by him.

The present-day known colloido-quantum complexities of the organism, and the linguistic difficulties of an organism-as-a-whole treatment, show the great need not only for collecting experimental data of all kinds but also for the production of

[1] Watanabe, Yisamu and Child, C. M., "The Longitudinal Gradient in Stylochus Ijimai; with a Critical Discussion." *Physiological Zoology*, Vol. VI, No. 4, 1933.

new theories of new structure which would more adequately cover the facts. When biologists acquire the permanent consciousness that they deal exclusively with absolute individuals and that all that is said of an organism which implies a denial of this is verbal fiction, a great many theoretical difficulties will automatically disappear. (See *Science and Sanity*.) Owing to the preliminary nature of these remarks, we cannot elaborate this point at present.

Recent attempts by E. S. Russell (1924 and 1934) to use the organism-as-a-whole treatment in describing the activities of organisms introduce new anthropomorphic tendencies by dragging in "meaning" where in animal life there is *no* "meaning" (although the *automatic* physico-chemical reaction has survival value), and make it obvious that biology needs a complete linguistic reformulation. The following discussion has a broader scope, as it offers a preliminary attempt to utilize a neutral non-elementalistic language which would be applicable to inanimate and animate nature, including man. Since the most recent research in general semantics, physico-mathematical sciences, and the work of Courtis [1] allow the application of mathematical and physico-mathematical methods to all processes this becomes feasible. The necessary linguistic revision of biology is bound to be very radical, because we cannot any longer preach the organism-as-a-whole and express those issues in the old elementalistic language. The meaning of the organism-as-a-whole will also have to be enlarged to non-elementalism, which applies equally to physics and biology. The revolutionary achievement of Einstein-Minkowski was the production of a new non-elementalistic language of space-time, similar in structure to the observed facts of nature. A similar revolution must be

[1] "Elsewhere the writer has shown (Courtis, S. A., "Maturation Units for the Measuring of Growth," *School and Society*, XXX, 1929) that for all biologic growth in which individual differences increase with age, so long as conditions remain constant (deterministic growth), the increases in the loglogs of the percentages of maturity are directly proportional to the increases in time. This is a universal law and may be used to *predict* growth under constant conditions in the scientific use of the term, prediction." Courtis, S. A., "The Prediction of Growth," *Journal of Educational Research*, XXVI, No. 7, 1933.

introduced into biology and the results are bound to be similar, namely the new language of new structure predicting and suggesting new facts which should lead to new experimental investigations. Investigations expressed in the old language of old structure conceal instead of suggest. Any language or any system must depend ultimately on undefined terms. The term *order*, with its derivatives, represents not only a non-elementalistic term but one of the most fundamental terms on which mathematics, mathematical physics, etc., and our new revision, must be based.

The problem considered in these investigations is essentially one of "organization" or "orderliness." Accordingly a preliminary consideration of orderliness in the living animal is pertinent.

The essential properties of protoplasm are due ultimately to its colloidal nature, and its energetic (dynamic) concomitants. When we consider this more in detail, it may be said to be made up of units of various levels of complexity. The electrons etc. belong to the primary level, the atoms, ions, etc. to the secondary level, and the molecules to the third level. Microscopically visible particles which result from the union of colloidal particles dependent on the above three levels give rise to various orders of increasing complexities. These colloidal units are all electrically charged, either positively or negatively, and make possible the dynamic interplays found in all living protoplasm. These dynamic centers and poles follow the same laws as those which regulate electro-magnetic poles. There are two kinds of poles, positive and negative. Here we have the first microscopic or macroscopic (cloud formation) levels of orderliness—a bipolarity orderliness. This makes possible regular diffusion currents between the poles, which are connected with the origins of cellular tissues. According to the findings of biophysicists (W. Seifriz, 1928), the structure of living matter is fibrous; it is made up of an interlacing mass of amino acid chains or slender crystalline "fibers." Here, then, we have on a higher level, cellular level, another level of orderliness.

On a still higher level, organ level, we have in at least the less highly integrated animals a unibilateral symmetry orderliness. Finally, this latter level of orderliness is characteristic of the body structure of the majority of living things.

There is still another level of orderliness which is seen in the ovum of many animals and also in the cœlenterates, ctenophores, and some echinoderms. This is multibilateral symmetry orderliness. In response to sperm penetration (the sperm is unibilaterally symmetrical), or in response to a suitable stimulus, such as a chemical change in the environment or the mechanical prick of a needle, we have a modification of the internal reaction system, involving a new dynamic arrangement of parts and a reintegration of the factors which produce the individual. In other words, we have a change from the more complex multibilateral symmetry orderliness of the ovum, to a more restricted pattern correlated with the less complex bilateral symmetry orderliness which characterizes the zygote.

It will be seen that all these levels of orderliness though different in complexity are fundamentally similar, their orientation being axial. Some investigators speak of a "unifying principle" as though it explained this semantic or leveling orderliness. What are the conditions which make possible this visible coördination (ordering) of events at various levels in development—that is our quest. At various levels we see different conditions but always orderly coördination. Each level gives rise to a succeeding level as a result of the emergence of a complexity of conditions of a higher order. Each level is characterized by its complexity of conditions and a correlated difference in complexity or dimensionality of orderliness. We are far from being in a position to inquire into the details of the mechanism of orderliness. Fundamentally this description is in agreement with Koffka (1924), who says concerning his view: "To many this view of the constitution of the most primitive phenomena will appear very odd indeed, for it assumes that a certain order dominates experience from the beginning. Whereas

we would be in much better agreement with current views if we were to assume that order comes only as a result of experience" (page 130).

It appears, then, that the use of terms—*order* and *levels* and their derivatives—in the analysis of the most complex biological phenomena unifies our efforts because mathematics and mathematical physics are based to a large extent on the term order, with well-known constructive results. Thus perhaps the application of such terms to biology, etc. may bring about constructive results where chaos prevailed. With this brief approach, let us consider the problem in hand:

Sea urchins found living on rocks have more powerful tube feet than those found on sand. The radially symmetrical arrangement of tube feet on the corona enables the sea urchin living on rocks to withstand dislodgement. It can cling on to the rock with its tube feet by almost all parts of its superficies. Those urchins found on the rocks generally move in almost any direction. Their behavior is multianial. In the case of those sea urchins which live on the sand, the tube feet have ceased to be the most efficient organs for relatively rapid locomotion and correlated with this we find: (1) other organs of locomotion are more commonly used, namely the spines; (2) the tube feet are less robust and tend to be used as tactile organs, "feelers," rather than as organs of locomotion; (3) the behavior of locomotion tends to be restricted, the animal moving in progressively fewer directions. The adult sea urchin as a whole, functional-structural, is the expression of a balance between inherited phylogenetic characters and inherited ontogenetic characters, which makes possible the survival of the animal. There are here two orders of inheritance; the former is a more primitive form, and of more ancient heritage, and therefore is more deeply ingrained in the whole body of the animal than is the latter—this order of inheritance may be considered to be closely associated with a lower level of integration, such as the submicroscopic or colloidal level; the latter is more intimately bound up with the macroscopic environment, both internal and external, of the animal, and in this sense is on a higher level of integration.

The adult Arbacia may be considered as being a sea urchin in which not only structure but function (locomotion) has changed from the first order to the second order. In other words, behavior as well as structure has become what may be called multibilateral.[1]

In the adult *Lytechinus* we find a partial arrest of functional symmetry, the more primitive uni-bilateral symmetry being maintained, whereas structure for the most part has become multi-bilaterally symmetrical. In the irregular sea urchins we find a complete arrest of functional uni-bilateral symmetry, together with an increasing arrest of structural uni-bilateral symmetry. Three stages in this gradual increasing arrest in structural uni-bilateral symmetry are seen in *Echinocardium cordatum*, *Lovenia elongata*, and finally in such forms as those found in the family *Pourtalesiïdæ*, respectively.

In adult *Echinoidea*, we find a series of changes from the condition found in *Arbacia*, which is structurally-functionally multi-bilaterally symmetrical, movement being multidirectional, to such forms as *Echinocardium cordatum* and *Echinarachnius parma*, which are structurally-functionally uni-bilaterally symmetrical, and where movement is unidirectional. The latter condition, structurally-functionally, is exactly what we find in the free-swimming larval echinoderm. In other words, we see in the Echinoidea evidence of a regression of functional-structural *ordinality*.

On the other hand, if by evolution we mean increasing specialization, then the Echinoidea may be considered as demonstrating a well-marked evolutionary series. The important point to notice is that there can be two interpretations of the observed "facts," which interpretations are not contradictory but intimately connected. They must be considered as such if we would have, ultimately, some more understanding of the sub-microscopic structure-function of any individual sea urchin.

It is thus exhibited more completely than heretofore that

[1] There is no fundamental difference between uni-bilateral symmetry and radial symmetry. The latter, which may be called multibilateral symmetry, is seen to be merely a different order of bilateral symmetry.

multibilateral symmetry of structure-function, in post-ovum development, is not primitive in the Echinoidea, but is a secondary development and ultimately tends to be replaced in their phylogeny by a primitive order of symmetry—a unibilateral symmetry.

Summary

Experimental evidence acquired by the author indicates that *Lytechinus variegatus*, *Echinometra lacunter*, *Strongylocentrotus dröbachiensis* are functionally bilaterally symmetrical. This evidence, together with observations made by various other investigators, shows that a bilaterally symmetrical organization (structure-function) is the inheritance of all the members of the Echinoidea.

The discussion draws attention to the fact that the structure of the language commonly used to describe biological phenomena does not correspond to the organism-as-a-whole, and non-elementalistic treatment of such phenomena, and therefore has not adequately described the observations of investigators nor their conclusions therefrom. A preliminary attempt has been made to overcome these linguistic difficulties by the use of the term *order* and its derivatives. There are different levels of orderliness in the dynamic structure-function of an organism which, though differing in complexity of conditions, are fundamentally similar. Confusion of these levels, or failure to recognize them, results in linguistically fictitious descriptions of happenings in nature.

It is more completely demonstrated that multi-bilateral symmetry of structure-function in post-ovum development is not primitive in the Echinoidea but is a secondary development, and ultimately tends to be replaced in their phylogeny by a primitive order of symmetry—a unibilateral symmetry.

* * *

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ELECTRICAL DISTRIBUTIONS ON CIRCULAR CYLINDERS. II

E. P. ADAMS

(Read by title Feb. 7, 1936)

1. The distribution of electricity on a pair of infinitely long circular cylinders at the same potential with given charges, or with a given difference of potential between them if the sum of the two charges is known, was obtained by the method of conformal transformation in a paper recently published in these *Proceedings*.[1] When the two cylinders are external to each other and placed in an electric field along or perpendicular to the line of centres, we can also obtain the solution in the form of Fourier's series. On comparing the two forms of solution we obtain developments of the Jacobian elliptic functions in Fourier's series. Many of these developments have been obtained by the method of contour integration [2] and so the results obtained in the previous paper may be confirmed.

When the two cylinders are brought into contact with each other it will be shown that the Fourier's series are transformed into Fourier's integrals. Comparison of these integrals with the solutions obtained in the previous paper leads to the evaluation of a number of definite integrals that have some interesting applications.

2. Let the complex potential, χ, be defined by

$$\chi = \varphi + i\psi,$$

in which φ is the potential and ψ the stream function. Let

$$w = u + iv,$$

where w is any function of $z = x + iy$, x and y being the

[1] LXXV, p. 11, 1935. This paper will be referred to as I.

[2] See particularly Schlomilch: *Compendium der Hohere Analysis*, Band II.

rectangular coördinates in the z-plane. If χ is any function of w it is known that both φ and ψ satisfy Laplace's equation in two dimensions,

$$\frac{\partial^2\varphi}{\partial u^2} + \frac{\partial^2\varphi}{\partial v^2} = 0.$$

We now take

$$z = if \cot \tfrac{1}{2}w. \tag{1}$$

Then (I, Art. 9) the curves given by $v = \alpha$ and $v = -\beta$ are two circles, external to each other, with centres on the x-axis, and radii

$$\left.\begin{aligned} a &= f \operatorname{cosech} \alpha, \\ b &= f \operatorname{cosech} \beta. \end{aligned}\right\} \tag{2}$$

The coördinates of any point in the z-plane corresponding to u, v are

$$\left.\begin{aligned} x &= \frac{f \sinh v}{\cosh v - \cos u}, \\ y &= \frac{f \sin u}{\cosh v - \cos u}. \end{aligned}\right\} \tag{3}$$

Let us take for χ the value given by [1]

$$\chi = Fz + 2Ffi\sum e^{-n\alpha}\frac{\sin n(w + i\beta)}{\sinh n(\alpha + \beta)}$$
$$+ 2Ffi\sum e^{-n\beta}\frac{\sin n(w - i\alpha)}{\sinh n(\alpha + \beta)}.$$

The infinite sums in this and the following expressions are always taken from $n = 1$ to $n = \infty$. We shall show that this value of χ is such that its real part, φ, has a constant value on each of the two circles, and that at the infinitely distant point of the z-plane it reduces to

$$\varphi = Fx + \text{const.}$$

Moreover, both its real and imaginary parts are solutions of Laplace's equation. This value of χ is therefore the solution for the problem of two unequal conducting circular cylinders

[1] Compare Bassett: *Hydrodynamics*, Vol. I, Art. 122.

placed in an electric field of intensity F along the line of centres.

Separating χ into its real and imaginary parts, we get, using (3),

$$\varphi = \frac{Ff\sinh v}{\cosh v - \cos u} - 2Ff\sum e^{-n\alpha}\frac{\sinh n(v+\beta)}{\sinh n(\alpha+\beta)}\cos nu$$
$$+ 2Ff\sum e^{-n\beta}\frac{\sinh n(\alpha - v)}{\sinh n(\alpha+\beta)}\cos nu,$$

$$\psi = \frac{Ff\sin u}{\cosh v - \cos u} + 2Ff\sum e^{-n\alpha}\frac{\cosh n(v+\beta)}{\sinh n(\alpha+\beta)}\sin nu$$
$$+ 2Ff\sum e^{-n\beta}\frac{\cosh n(\alpha - v)}{\sinh n(\alpha+\beta)}\sin nu.$$

When $v = \alpha$, on the cylinder of radius a,

$$\varphi_a = \frac{Ff\sinh\alpha}{\cosh\alpha - \cos u} - 2Ff\sum e^{-n\alpha}\cos nu,$$

and on the cylinder of radius b, with $v = -\beta$,

$$\varphi_b = -\frac{Ff\sinh\beta}{\cosh\beta - \cos u} + 2Ff\sum e^{-n\beta}\cos nu.$$

By Fourier's theorem, we have

$$\frac{\sinh\alpha}{\cosh\alpha - \cos u} = \frac{1}{2}a_0 + \sum a_n \cos nu,$$

where

$$a_n = \frac{\sinh\alpha}{\pi}\int_0^{2\pi}\frac{\cos nu\cdot du}{\cosh\alpha - \cos u} = 2e^{-n\alpha}.$$

Therefore

$$\frac{\sinh\alpha}{\cosh\alpha - \cos u} = 1 + 2\sum e^{-n\alpha}\cos nu. \tag{4}$$

There is a similar development when α is replaced by β. It therefore follows that $\varphi_a = Ff$, $\varphi_b = -Ff$, and the difference of potential between the two cylinders is accordingly

$$V = 2Ff.$$

Since $\psi = 0$ for both $u = 0$ and $u = \pi$, the charges vanish on each cylinder. At the infinitely distant point in the z-plane,

$u = v = 0$, and therefore at this point

$$\varphi = Fx - Ff\sum \frac{\sinh n(\alpha - \beta)}{\sinh n(\alpha + \beta)} = Fx + \text{const.},$$
$$\psi = Fy.$$

We can bring the two cylinders to the same potential by placing line charges, $\pm Q'$, at the inverse points in the two circles; the complex potential arising from these line charges is

$$\chi = 2iQ'w,$$

and the resulting difference of potential between the two cylinders is

$$V = -2Q'(\alpha + \beta).$$

If we now take Q' to be given by the equation

$$Q' = \frac{Ff}{\alpha + \beta},$$

then the two cylinders will be at the same potential in the field F, with equal and opposite induced charges,

$$Q_a = -Q_b = \frac{Ff}{\alpha + \beta}.$$

This agrees with the result found by the method of conformal transformation in I (65).

For two unequal cylinders, both at potential 0, in a field of force along the line of centres, we accordingly have

$$\varphi = Ff\left\{\frac{\sinh v}{\cosh v - \cos u} - \frac{2v}{\alpha + \beta} + \frac{\alpha - \beta}{\alpha + \beta} - 2\sum e^{-n\alpha}\frac{\sinh n(v + \beta)}{\sinh n(\alpha + \beta)}\cos nu + 2\sum e^{-n\beta}\frac{\sinh n(\alpha - v)}{\sinh n(\alpha + \beta)}\cos nu\right\}. \quad (5)$$

and

$$\psi = Ff\left\{\frac{\sin u}{\cosh v - \cos u} + \frac{2u}{\alpha + \beta} + 2\sum e^{-n\alpha}\frac{\cosh n(v + \beta)}{\sinh n(\alpha + \beta)}\sin nu + 2\sum e^{-n\beta}\frac{\cosh n(\alpha - v)}{\sinh n(\alpha + \beta)}\sin nu\right\}. \quad (6)$$

The surface density of the distribution of electricity on the cylinder of radius a is given by

$$4\pi f\sigma_a = (\cosh\alpha - \cos u)\frac{\partial\varphi}{\partial v}, \qquad v = \alpha.$$

Therefore we find

$$\sigma_a = -\frac{F}{4\pi}\left\{\frac{\cosh\alpha\cos u - 1}{(\cosh\alpha - \cos u)^2} + \frac{2}{\alpha+\beta} + 2\sum ne^{-n\alpha}\coth n(\alpha+\beta)\cos nu + 2\sum ne^{-n\beta}\operatorname{csch} n(\alpha+\beta)\cos nu\right\}(\cosh\alpha - \cos u). \quad (7)$$

For two cylinders of equal radii, $\alpha = \beta$, and we have

$$\varphi = Ff\left\{\frac{\sinh v}{\cosh v - \cos u} - \frac{v}{\alpha} - 2\sum e^{-n\alpha}\frac{\sinh nv}{\sinh n\alpha}\cos nu\right\}, \quad (8)$$

$$\psi = Ff\left\{\frac{\sin u}{\cosh v - \cos u} + \frac{u}{\alpha} + 2\sum e^{-n\alpha}\frac{\cosh nv}{\sinh n\alpha}\sin nu\right\}, \quad (9)$$

and

$$\sigma_a = -\frac{F}{4\pi}\left\{\frac{\cosh\alpha\cos u - 1}{(\cosh\alpha - \cos u)^2} + \frac{1}{\alpha} + 2\sum ne^{-n\alpha}\coth n\alpha\cos nu\right\}(\cosh\alpha - \cos u). \quad (10)$$

The plane $x = 0$ is now at potential 0, and so if it be made a conducting surface, we shall have the solution of the problem of a freely charged infinite plane in front of which is placed a long cylinder parallel to the plane and at the same potential. The surface density on the cylinder is given by (10), and that on the plane by

$$\sigma = -\frac{F}{4\pi}\left\{\frac{1}{1 - \cos u} - \frac{1}{\alpha} - 2\sum ne^{-n\alpha}\frac{\cos nu}{\sinh n\alpha}\right\}(1 - \cos u). \quad (11)$$

3. When the two unequal cylinders are placed in a field perpendicular to the line of centres, we shall show that the

complex potential given by

$$\chi = -iFz - 2iFf\sum e^{-n\alpha}\frac{\cos n(w+i\beta)}{\sinh n(\alpha+\beta)} + 2iFf\sum e^{-n\beta}\frac{\cos n(w-i\alpha)}{\sinh n(\alpha+\beta)}$$

satisfies all the conditions of the problem. We find

$$\varphi = Fy - 2Ff\sum e^{-n\alpha}\frac{\sinh n(v+\beta)}{\sinh n(\alpha+\beta)}\sin nu + 2Ff\sum e^{-n\beta}\frac{\sinh n(v-\alpha)}{\sinh n(\alpha+\beta)}\sin nu, \quad (12)$$

and

$$\psi = -Fx - 2Ff\sum e^{-n\alpha}\frac{\cosh n(v+\beta)}{\sinh n(\alpha+\beta)}\cos nu + 2Ff\sum e^{-n\beta}\frac{\cosh n(v-\alpha)}{\sinh n(\alpha+\beta)}\cos nu. \quad (13)$$

At the infinitely distant point of the z-plane the potential reduces to

$$\varphi = Fy.$$

On the cylinder of radius a,

$$\varphi_a = Ff\left\{\frac{\sin u}{\cosh\alpha - \cos u} - 2\sum e^{-n\alpha}\sin u\right\},$$

and on the cylinder of radius b,

$$\varphi_b = Ff\left\{\frac{\sin u}{\cosh\beta - \cos u} - 2\sum e^{-n\beta}\sin nu\right\}.$$

By Fourier's theorem,

$$\frac{\sin u}{\cosh\alpha - \cos u} = \sum b_n \sin nu,$$

where

$$b_n = \frac{1}{\pi}\int_0^{2\pi}\frac{\sin u \sin nu}{\cosh\alpha - \cos u}\,du = 2e^{-n\alpha}.$$

Therefore

$$\frac{\sin u}{\cosh\alpha - \cos u} = 2\sum e^{-n\alpha}\sin nu, \quad (14)$$

and accordingly

$$\varphi_a = \varphi_b = 0.$$

The charges induced on half the cylinders are, per unit length, Q_a and Q_b, where

$$4\pi Q_a = \psi(u = \pi) - \psi(u = 0) \quad \text{for} \quad v = \alpha.$$

So we find

$$Q_a = \frac{Ff}{2\pi}\left\{\operatorname{csch}\alpha + 2\sum e^{-(2n-1)\alpha}\coth(2n-1)(\alpha+\beta) - 2\sum e^{-(2n-1)\beta}\operatorname{csch}(2n-1)(\alpha+\beta)\right\}. \quad (15)$$

By interchanging α and β we get Q_b.

The surface density on the cylinder of radius a is given by

$$\sigma_a = -\frac{F}{4\pi}\left\{\frac{\sinh\alpha\sin u}{(\cosh\alpha - \cos u)^2} + 2\sum ne^{-n\alpha}\coth n(\alpha+\beta)\sin nu - 2\sum ne^{-n\beta}\operatorname{csch} n(\alpha+\beta)\sin nu\right\}(\cosh\alpha - \cos u). \quad (16)$$

If the two cylinders have equal radii we can write

$$\varphi = Fy - 2Ff\sum e^{-n\alpha}\frac{\cosh nv}{\cosh n\alpha}\sin nu, \quad (17)$$

$$\psi = -Fx - 2Ff\sum e^{-n\alpha}\frac{\sinh nv}{\cosh n\alpha}\cos nu, \quad (18)$$

$$Q_a = -\frac{Ff}{2\pi}\left\{\operatorname{csch}\alpha + 2\sum e^{-(2n-1)\alpha}\tanh(2n-1)\alpha\right\}, \quad (19)$$

and

$$\sigma_a = -\frac{F}{4\pi}\left\{\frac{\sinh\alpha\sin u}{(\cosh\alpha - \cos u)^2} + 2\sum ne^{-n\alpha}\tanh n\alpha\sin nu\right\}(\cosh\alpha - \cos u). \quad (20)$$

Whether or not the two cylinders have equal radii the x-axis is at potential 0; it may therefore be made a conducting surface. On the portion of it between the two cylinders,

$u = \pi$, and we have for the surface density

$$\sigma = -\frac{F}{4\pi}\left\{\frac{1}{\cosh v + 1} + 2\sum(-1)^n n e^{-n\alpha}\frac{\sinh n(v+\beta)}{\sinh n(\alpha+\beta)} - 2\sum(-1)^n n e^{-n\beta}\frac{\sinh n(v-\alpha)}{\sinh n(\alpha+\beta)}\right\}(\cosh v + 1). \quad (21)$$

For cylinders of equal radii this becomes

$$\sigma = -\frac{F}{4\pi}\left\{\frac{1}{\cosh v + 1} + 2\sum(-1)^n n e^{-n\alpha}\frac{\cosh nv}{\cosh n\alpha}\right\}(\cosh v + 1). \quad (22)$$

On the portions of the x-axis external to the two cylinders, $u = 0$, and the surface density is

$$\sigma = -\frac{F}{4\pi}\left\{\frac{1}{\cosh v - 1} - 2\sum n e^{-n\alpha}\frac{\sinh n(v+\beta)}{\sinh n(\alpha+\beta)} + 2\sum n e^{-n\beta}\frac{\sinh n(v-\alpha)}{\sinh n(\alpha+\beta)}\right\}(\cosh v - 1), \quad (23)$$

which becomes, for the case of equal cylinders,

$$\sigma = -\frac{F}{4\pi}\left\{\frac{1}{\cosh v - 1} - 2\sum n e^{-n\alpha}\frac{\cosh nv}{\cosh n\alpha}\right\}(\cosh v - 1). \quad (24)$$

The charge on the portion of the x-axis between the two cylinders is

$$Q = \frac{Ff}{4\pi}\left\{\tanh\frac{\alpha}{2} + \tanh\frac{\beta}{2} + 2\sum(-1)^n(e^{-n\alpha} + e^{-n\beta})\tanh\frac{n}{2}(\alpha+\beta)\right\}. \quad (25)$$

For equal cylinders this charge is

$$Q = \frac{Ff}{2\pi}\left\{\tanh\frac{\alpha}{2} + 2\sum(-1)^n e^{-n\alpha}\tanh n\alpha\right\}. \quad (26)$$

4. We shall now compare the results that have just been obtained with the corresponding expressions in terms of elliptic functions that were obtained in the previous paper. We begin with equal cylinders in an electric field along the line

of centres. The complex potential, obtained from I (64) by putting $\delta = 0$, is

$$\chi = \frac{2FfK'}{\pi} Z(\lambda) + iFf\frac{K'}{K}.$$

By I (35),

$$\lambda = -i\frac{K'w}{\pi} + iK' = \frac{K'v}{\pi} + iK'\left(1 - \frac{u}{\pi}\right),$$

and

$$\alpha = \frac{\pi K}{K'}.$$

The addition theorem for the Zeta function is

$$Z(u + v) = Z(u) + Z(v) - k^2 \, sn\, u \, sn\, v \, sn(u + v). \quad (27)$$

We have also

$$iZ(iu) = -\frac{sn(u, k')dn(u, k')}{cn(u, k')} + \frac{\pi u}{2KK'} + Z(u, k'). \quad (28)$$

In all expressions for elliptic functions the modulus k is to be understood unless the complementary modulus k' is indicated. We can now separate χ into its real and imaginary parts; equating these to (8) and (9), we find

$$\frac{2K'}{\pi}\left\{Z(v') + \frac{sn\, v' \, cn\, v' \, dn\, v' \, cn^2(u', k')}{sn^2 v' + cn^2 v' \, sn^2(u', k')}\right\}$$
$$= \frac{\sinh v}{\cosh v - \cos u} - \frac{v}{\alpha} - 2\sum e^{-n\alpha}\frac{\sinh nv}{\sinh n\alpha}\cos nu, \quad (29)$$

and

$$\frac{2K'}{\pi}\left\{Z(u', k') + \frac{cn^2 v' \, sn(u', k')cn(u', k')dn(u', k')}{sn^2 v' + cn^2 v' \, sn^2(u', k')}\right\}$$
$$= \frac{\sin u}{\cosh v - \cos u} + 2\sum e^{-n\alpha}\frac{\cosh nv}{\sinh n\alpha}\sin nu. \quad (30)$$

For abbreviation, we have used

$$u' = \frac{K'u}{\pi} = \frac{Ku}{\alpha},$$

and (31)

$$v' = \frac{K'v}{\pi} = \frac{Kv}{\alpha}.$$

For a point on the cylinder of radius a, $v = \alpha$, $v' = K$. So, referring to (4), we see that (29) is identically satisfied; (30) becomes, with the aid of (14),

$$\frac{2K'}{\pi} Z\left(\frac{K'u}{\pi}, k'\right) = 2\sum e^{-n\alpha}(1 + \coth n\alpha) \sin nu.$$

In the theory of elliptic functions the q function is defined by

$$q = e^{-\pi K'/K}.$$

We shall define the complementary function, q', by

$$q' = e^{-\pi K/K'}.$$

The value of q for a modular angle θ is equal to the value of q' for the modular angle $(\pi/2) - \theta$. Thus q is small for small modular angles and q' is small for large modular angles. We can now write

$$\frac{K'}{\pi} Z\left(\frac{K'u}{\pi}, k'\right) = 2\sum \frac{q'^n}{1 - q'^{2n}} \sin nu,$$

or, changing to the complementary modulus, and writing x for Ku/π,

$$Z(x) = \frac{2\pi}{K} \sum \frac{q^n}{1 - q^{2n}} \sin \frac{n\pi x}{K}. \tag{32}$$

This is the known Fourier expansion for the Jacobian Zeta function.

Next, let $u = 0$ in (29); this corresponds to a point on the x-axis outside of the two cylinders. Then $u' = 0$, and

$$Z(x) = -\frac{\pi x}{2KK'} + \frac{\pi}{2K'} \coth \frac{\pi x}{2K'} - \frac{cn\, x\, dn\, x}{sn\, x} - \frac{2\pi}{K'} \sum \frac{q'^{2n}}{1 - q'^{2n}} \sinh \frac{n\pi x}{K'}, \tag{33}$$

where we have written x for $K'v/\pi$. Similarly, if we take $u = \pi$, corresponding to a point on the x-axis between the

two cylinders, we find

$$Z(x) = -\frac{\pi x}{2KK'} + \frac{\pi}{2K'}\tanh\frac{\pi x}{2K'} - \frac{2\pi}{K'}\sum(-1)^n\frac{q'^{2n}}{1-q'^{2n}}\sinh\frac{n\pi x}{K'}. \quad (34)$$

Since our solutions have been obtained for the region of the z-plane external to the two cylinders we must have

$$-\alpha \leq v \leq \alpha,$$

or

$$-K \leq x \leq K.$$

Let us write ix for x in (33) and in (34). Using (28), we get, on changing to the complementary modulus,

$$Z(x) + \frac{cn\,x\,dn\,x}{sn\,x} = \frac{\pi}{2K}\cot\frac{\pi x}{2K} + \frac{2\pi}{K}\sum\frac{q^{2n}}{1-q^{2n}}\sin\frac{n\pi x}{K}, \quad (35)$$

and

$$Z(x) - \frac{sn\,x\,dn\,x}{cn\,x} = -\frac{\pi}{2K}\tan\frac{\pi x}{2K} + \frac{2\pi}{K}\sum(-1)^n\frac{q^{2n}}{1-q^{2n}}\sin\frac{n\pi x}{K}. \quad (36)$$

Subtracting (36) from (35) we find

$$\frac{K}{\pi}\frac{dn\,x}{sn\,x\,cn\,x} = \csc\frac{\pi x}{K} + 4\sum\frac{q^{2(2n-1)}}{1-q^{2(2n-1)}}\sin(2n-1)\frac{\pi x}{K}. \quad (37)$$

If we put $x = eK$ in (34) we get, in a form suitable for numerical computation,

$$Z(eK) = \frac{\pi}{2K'}\left\{-e + \frac{1-q'^e}{1+q'^e} - 2\sum(-1)^n q'^{n(2-e)}\frac{1-q'^{2ne}}{1-q'^{2n}}\right\}. \quad (38)$$

This series converges rapidly for large modular angles, even for values of e that are nearly unity. Subtracting (34) from

(33) we get, with $x = eK$,

$$\frac{cn\, eK\; dn\, eK}{sn\, eK}$$
$$= \frac{2\pi}{K'}\left\{\frac{q'^{e}}{1 - q'^{2e}} - \sum q'^{(2n-1)(2-e)}\frac{1 - q'^{2(2n-1)e}}{1 - q'^{2(2n-1)}}\right\}. \tag{39}$$

If we put $v = \alpha/2$ in (29) we get, on changing to the complementary modulus,

$$\frac{4K}{\pi}\left\{\frac{1 - k}{2} + \frac{k\, cn^2 x}{1 + k\, sn^2 x}\right\} = 1 + 4\sum\frac{q^{n/2}}{1 + q^n}\cos\frac{n\pi x}{K}, \tag{40}$$

and from (30) in the same way,

$$\frac{K}{\pi}\left\{Z(x) + \frac{k\, sn\, x\, cn\, x\, dn\, x}{1 + k\, sn^2 x}\right\} = \sum\frac{q^{n/2}}{1 - q^n}\sin\frac{n\pi x}{K}. \tag{41}$$

We next compare the two different expressions for the surface density of the charge induced upon the cylinder $v = \alpha$ when the two equal cylinders, at the same potential, are placed in a field along the line of centres. Equating the value of σ_a derived from I (34), with $\delta = 0$, to its value given in (8) above, we get

$$\frac{1}{\alpha} - \frac{1 - \cosh\alpha\cos u}{(\cosh\alpha - \cos u)^2} + 2\sum n e^{-n\alpha}\coth n\alpha\cos nu$$
$$= \frac{2K'^2}{\pi^2 K}\left\{E - Kk'^2\, sn^2\left(\frac{Ku}{\alpha}, k'\right)\right\}.$$

Differentiate (4) with respect to α:

$$\frac{\cosh\alpha\cos u - 1}{(\cosh\alpha - \cos u)^2} = 2\sum n e^{-n\alpha}\cos nu.$$

Remembering that

$$KE' + K'E - KK' = \pi/2,$$

we find, on changing to the complementary modulus,

$$k^2\, sn^2 x = \frac{K - E}{K} - \frac{2\pi^2}{K^2}\sum\frac{nq^n}{1 - q^{2n}}\cos\frac{n\pi x}{K}. \tag{42}$$

In the case just considered the plane $x = 0$ is at the same

potential as the cylinders; it may therefore be made a conducting plane, and the surface density at any point defined by u may easily be derived from I, Art. 21. The result is

$$\sigma = -\frac{FK'^2}{2\pi^3 K}\left\{K - E + K\frac{cn^2(u', k')}{sn^2(u', k')}\right\}.$$

If this be equated to (11) we get, on changing to the modulus k,

$$\frac{cn^2 x}{sn^2 x} = -\frac{E}{K} + \frac{\pi^2}{4K^2}\csc^2\frac{\pi x}{2K} - \frac{2\pi^2}{K^2}\sum\frac{nq^{2n}}{1 - q^{2n}}\cos\frac{n\pi x}{K}. \quad (43)$$

Since $cn^2 x = 1 - sn^2 x$, we can write

$$\frac{1}{sn^2 x} = 1 - \frac{E}{K} + \frac{\pi^2}{4K^2}\csc^2\frac{\pi x}{2K} - \frac{2\pi^2}{K^2}\sum\frac{nq^{2n}}{1 - q^{2n}}\cos\frac{n\pi x}{K}. \quad (44)$$

5. The complex potential for two equal cylinders in a field perpendicular to the line of centres is given by

$$\chi = i\frac{2FfK'k}{\pi}sn\,\lambda.$$

This may be derived from the general expression in I, Art. 19 on going to the limit with $\delta = 0$; it may also be derived directly very easily. Equating the real and the imaginary parts to (17) and (18) we find

$$2\frac{K'}{\pi}\frac{\{1 - sn^2(u', k')dn^2 v'\}sn(u', k')cn(u', k')cn\,v'\,dn\,v'}{dn^2(u', k')sn^2 v' + sn^2(u', k')cn^2(u', k')cn^2 v'\,dn^2 v'}$$
$$= \frac{\sin u}{\cosh v - \cos u} - 4\sum\frac{q'^{2n}}{1 + q'^{2n}}\cosh nv \sin nu, \quad (45)$$

$$2\frac{K'}{\pi}\frac{\{1 - sn^2(u', k')dn^2 v'\}dn(u', k')sn\,v'}{dn^2(u', k')sn^2 v' + sn^2(u', k')cn^2(u', k')cn^2 v'\,dn^2 v'}$$
$$= \frac{\sinh v}{\cosh v - \cos u} + 4\sum\frac{q'^{2n}}{1 + q'^{2n}}\sinh nv \cos nu. \quad (46)$$

These expressions are valid for

$$-\alpha \leq v \leq \alpha,$$
$$-\pi \leq u \leq \pi.$$

Put $v = 0$ in (45) and we get, with the modulus k,

$$2\frac{K}{\pi}\frac{cn\,x}{sn\,x} = \cot\frac{\pi x}{2K} - 4\sum\frac{q^{2n}}{1+q^{2n}}\sin\frac{n\pi x}{K}. \qquad (47)$$

Replace x by $K - x$ and we get

$$\frac{2Kk'}{\pi}\frac{sn\,x}{cn\,x} = \tan\frac{\pi x}{2K} + 4\sum(-1)^n\frac{q^{2n}}{1+q^{2n}}\sin\frac{n\pi x}{K}. \qquad (48)$$

If we write ix for x, and change to the complementary modulus, we get from (47) and (48)

$$\frac{1}{sn\,eK} = \frac{\pi}{2K'}\left\{\frac{1+q'^e}{1-q'^e} + 2\sum q'^{n(2-e)}\frac{1-q'^{2ne}}{1+q'^{2n}}\right\}, \qquad (49)$$

and

$$sn\,eK = \frac{\pi}{2kK'}\left\{\frac{1-q'^e}{1+q'^e} + 2\sum(-1)^n q'^{n(2-e)}\frac{1-q'^{2ne}}{1+q'^{2n}}\right\}. \qquad (50)$$

These expressions are useful for large modular angles. e is defined in them by $x = eK$.

With $v = \alpha/2$ in (45) and (46), we find

$$\frac{Kk}{\pi}(1+k)^{\frac{1}{2}}\frac{sn\,x\,cn\,x}{1+k\,sn^2 x} = \sum q^{n/2}\frac{1-q^n}{1+q^{2n}}\sin\frac{n\pi x}{K}, \qquad (51)$$

and

$$\frac{2K}{\pi}(1+k)^{\frac{1}{2}}\frac{dn\,x}{1+k\,sn^2 x} = 1 + 2\sum q^{n/2}\frac{1+q^n}{1+q^{2n}}\cos\frac{n\pi x}{K}. \qquad (52)$$

$z = \alpha$ in (46) gives, in the same way,

$$\frac{2K}{\pi}dn\,x = 1 + 4\sum\frac{q^n}{1+q^{2n}}\cos\frac{n\pi x}{K}. \qquad (53)$$

Putting $K - x$ for x, we find

$$\frac{2Kk'}{\pi}\frac{1}{dn\,x} = 1 + 4\sum(-1)^n\frac{q^n}{1+q^{2n}}\cos\frac{n\pi x}{K}. \qquad (54)$$

If in (46) we put $u = 0$ and $u = \pi$ we find (49) and (50)

again. With $u = \pi/2$ in (45) we get, with the same notation,

$$\frac{2K'k^{\frac{1}{2}}}{\pi}\frac{cn\,eK\,dn\,eK}{1 + k\,sn^2\,eK}$$
$$= \frac{2q'^{e}}{1 + q'^{2e}} + 2\sum(-1)^n q'^{(2n-1)(2-e)}\frac{1 + q'^{2(2n-1)e}}{1 + q'^{2(2n-1)}}. \quad (55)$$

$u = \pi/2$ in (46) gives

$$\frac{2K'k^{\frac{1}{2}}(1 + k)}{\pi}\frac{sn\,eK}{1 + k\,sn^2\,eK} = \frac{1 - q'^{2e}}{1 + q'^{2e}}$$
$$+ 2\sum(-1)^n q'^{2n(2-e)}\frac{1 - q'^{4ne}}{1 + q'^{4n}}. \quad (56)$$

We now compare the value of the surface density on one of the two equal cylinders when placed in a field perpendicular to the line of centres given by I (60) with (20) above, and we get

$$\frac{2K'^2k'^2}{\pi^2}cn(u', k')sn(u', k') = \frac{\sinh\alpha\sin u}{(\cosh\alpha - \cos u)^2}$$
$$+ 2\sum ne^{-n\alpha}\tanh n\alpha \sin nu.$$

Differentiating (14) with respect to α, we get

$$\frac{\sinh\alpha\sin u}{(\cosh\alpha - \cos u)^2} = 2\sum ne^{-n\alpha}\sin nu,$$

and, accordingly,

$$cn\,x\,sn\,x = \frac{2\pi^2}{K^2k^2}\sum\frac{nq^n}{1 + q^{2n}}\sin\frac{n\pi x}{K}. \quad (57)$$

This may also be obtained by differentiating (53).

If the x-axis represent a conducting plane we have for the surface density on the portion of it between the two cylinders, by I, Art. 19,

$$\sigma = \frac{FK'^2k}{2\pi^3}cn\,v'\,dn\,v'(\cosh v + 1).$$

Equating this to (22), we get

$$2\frac{K'^2k}{\pi^2}cn\,x\,dn\,x = \frac{1}{2}\operatorname{sech}^2\frac{\pi x}{2K'} + 4\sum(-1)^n\frac{nq'^{2n}}{1 + q'^{2n}}\cosh\frac{n\pi x}{K'}.$$

Putting $x = eK$ we may write

$$cn\, eK\, dn\, eK = \frac{\pi^2}{K'^2}\left\{\frac{q'^e}{(1+q'^e)^2} + \sum(-1)^n n q'^{n(2-e)} \frac{1+q'^{2ne}}{1+q'^{2n}}\right\}. \quad (58)$$

Writing ix for x and changing to the complementary modulus we find

$$\frac{4K^2k'}{\pi^2}\frac{dn\, x}{cn^2\, x} = \sec^2\frac{\pi x}{2K} + 8\sum(-1)^n \frac{nq^{2n}}{1+q^{2n}}\cos\frac{n\pi x}{K}. \quad (59)$$

In a similar way, for the portions of the plane outside the two cylinders we get

$$\frac{2K'^2}{\pi^2}\frac{cn\, x\, dn\, x}{sn^2\, x} = \frac{1}{2}\operatorname{csch}^2\frac{\pi x}{2K'} - 4\sum\frac{nq'^{2n}}{1+q'^{2n}}\cosh\frac{n\pi x}{K'}. \quad (60)$$

Or, with $x = eK$,

$$\frac{K'^2}{\pi^2}\frac{cn\, eK\, dn\, eK}{sn^2\, eK} = \frac{q'^e}{(1-q'^e)^2} - \sum n q'^{n(2-e)}\frac{1+q'^{2ne}}{1+q'^{2n}}. \quad (61)$$

And with ix replacing x,

$$4\frac{K^2}{\pi^2}\frac{dn\, x}{sn^2\, x} = \csc^2\frac{\pi x}{2K} + 8\sum\frac{nq^{2n}}{1+q^{2n}}\cos\frac{n\pi x}{K}. \quad (62)$$

6. In the general case of two unequal cylinders we shall consider some special cases in order to confirm the results obtained in the previous paper. For two unequal cylinders in a field along the line of centres, we have, from I (64),[1]

$$\chi = \frac{2FfK'}{\pi}\left\{\frac{k\, sn\,\delta\, cn\,\lambda\, dn\,\lambda}{1+k\, sn\,\delta\, sn\,\lambda} + Z(\lambda)\right\} + iFf\frac{K'}{K}.$$

This value of χ makes the potential vanish over both conductors. At the origin of coördinates, $\lambda = -\delta$, and so we have at this point

$$\varphi = \frac{2FfK'}{\pi}\left\{\frac{k\, sn\,\delta\, cn\,\delta\, dn\,\delta}{1-k\, sn^2\,\delta} - Z(\delta)\right\},$$

[1] There is an error in this expression as given in I. The factor k was omitted from the first term on the right as well as from the corresponding term in (62).

and

$$\psi = Ff\frac{K'}{K} = 2\pi Q.$$

At the origin, $u = \pi$, $v = 0$, and so from (5) and (6),

$$\varphi = Ff\left\{\frac{\delta}{K} - 2\Sigma(-1)^n\frac{e^{-n\alpha}\sinh n\beta - e^{-n\beta}\sinh n\alpha}{\sinh n(\alpha+\beta)}\right\},$$

and

$$\psi = Ff\frac{2\pi}{\alpha+\beta}.$$

We have already seen that the two values of ψ agree. Since by I (38)

$$\alpha = \pi\frac{K}{K'} + \frac{\pi\delta}{K'}$$

and

$$\beta = \pi\frac{K}{K'} - \frac{\pi\delta}{K'},$$

we can write, putting x for δ,

$$2\frac{K'}{\pi}\left\{\frac{k\,sn\,x\,cn\,x\,dn\,x}{1-k\,sn^2 x} - Z(x)\right\}$$
$$= \frac{x}{K} + 4\Sigma(-1)^n\frac{q'^{2n}}{1-q'^{4n}}\sinh\frac{2n\pi x}{K'}. \quad (63)$$

This is valid for all values of x between $-K$ and K. Putting ix for x and changing to the complementary modulus, we have

$$\frac{2K}{\pi}\left\{Z(x) - \frac{(1-k')\,sn\,x\,cn\,x\,dn\,x}{1-(1-k')sn^2 x}\right\}$$
$$= 4\Sigma(-1)^n\frac{q^{2n}}{1-q^{4n}}\sin\frac{2n\pi x}{K}. \quad (64)$$

In a field perpendicular to the line of centres the charge induced on half the cylinder of radius a is given in I, Art. 19,

$$Q = \frac{FfK'}{2\pi^2}\,\frac{(1-k)cn\,\delta\,dn\,\delta}{(1+sn\,\delta)(1+k\,sn\,\delta)}.$$

Equating this to (15) we find

$$\frac{K'(1-k)}{4\pi}\,\frac{cn\,x\,dn\,x}{(1+sn\,x)(1+k\,sn\,x)}$$
$$=\sum\frac{q'^{2n-1}}{1-q'^{4(2n-1)}}\left\{(1-q'^{2(2n-1)})\cosh(2n-1)\frac{\pi x}{K'}\right.$$
$$\left.-(1+q'^{2(2n-1)})\sinh(2n-1)\frac{\pi x}{K'}\right\}. \quad (65)$$

where we have again written x for δ. If we write ix for x in (65) and separate into the real and the imaginary parts we find, after changing to the complementary modulus,

$$\frac{K(1-k')}{4\pi}\,\frac{1-(1+k')sn^2\,x}{dn\,x}$$
$$=\sum\frac{q^{2n-1}}{1+q^{2(2n-1)}}\cos(2n-1)\frac{\pi x}{K}, \quad (66)$$

and

$$\frac{Kk^2}{4\pi}\,\frac{cn\,x\,sn\,x}{dn\,x}=\sum\frac{q^{2n-1}}{1-q^{2(2n-1)}}\sin(2n-1)\frac{\pi x}{K}. \quad (67)$$

(66) may also be obtained by subtracting (53) and (54). Since the x-axis is now at the constant potential 0 it may be made a conducting surface, and the charge on the portion of it between the two cylinders, as given by I, Art. 19,[1] is

$$Q=\frac{FfK'k}{\pi^2}\,\frac{cn\,\delta}{dn\,\delta}.$$

If we equate this expression to (25) and proceed in the same way as in the previous examples we shall again get (52).

7. The various series for elliptic functions that have been derived may be tested by giving special values to the arguments. In this way we obtain a number of numerical series in terms of the q-functions that were first given by Jacobi. A few illustrations will now be given.

With $x = K/2$ in (32) or in (67),

$$\frac{K(1-k')}{4\pi}=\sum(-1)^{n-1}\frac{q^{2n-1}}{1-q^{2(2n-1)}}. \quad (68)$$

[1] There is an error in I. In this formula K' should replace K'^2.

With $x = K/2$ in (35) or (36),

$$\frac{K(1 + k')}{4\pi} = \frac{1}{4} + \Sigma(-1)^{n+1}\frac{q^{2(2n-1)}}{1 - q^{2(2n-1)}}. \tag{69}$$

Adding and subtracting, we find

$$2\frac{K}{\pi} = 1 - 4\Sigma(-1)^n\frac{q^{2n-1}}{1 - q^{2(2n-1)}}, \tag{70}$$

and

$$\frac{2Kk'}{\pi} = 1 + 4\Sigma(-1)^n\frac{q^{2n-1}}{1 + q^{2(2n-1)}}. \tag{71}$$

Put $e = 1/2$ in (39),

$$\frac{2Kk}{\pi} = 4q^{\frac{1}{2}}\Sigma\frac{q^{n-1}}{1 + q^{2n-1}}. \tag{72}$$

With $x = 0$ and $x = K$ in (40),

$$2\frac{K}{\pi}(1 + k) = 1 + 4\Sigma\frac{q^{n/2}}{1 + q^n}, \tag{73}$$

and

$$2\frac{K}{\pi}(1 - k) = 1 + 4\Sigma(-1)^n\frac{q^{n/2}}{1 + q^n}. \tag{74}$$

Adding (73) and (74), we get

$$2\frac{K}{\pi} = 1 + 4\Sigma\frac{q^n}{1 + q^{2n}}. \tag{75}$$

Compare (70).
If we subtract we get (72).

If we put $x = K/2$ in (40), we find

$$\frac{2Kk'}{\pi} = 1 + 4\Sigma(-1)^n\frac{q^n}{1 + q^{2n}}. \tag{76}$$

Compare (71).
With $x = K/2$ in (41),

$$2\frac{Kk}{\pi} = 4q^{\frac{1}{2}}\Sigma(-1)^{n+1}\frac{q^{n-1}}{1 - q^{2n-1}}. \tag{77}$$

Compare (72).
$x = 0$ in (42) gives

$$\frac{4K(K-E)}{\pi^2} = 8\sum \frac{nq^n}{1-q^{2n}}. \tag{78}$$

$x = K$ in (44) gives

$$\frac{4}{\pi^2}KE = 1 - 8\sum(-1)^n \frac{nq^{2n}}{1-q^{2n}}. \tag{79}$$

Adding, we find

$$4\frac{K^2}{\pi^2} = 1 + 8\sum \frac{nq^n}{1+(-q)^n}. \tag{80}$$

With $x = K/2$ in (47) or (48),

$$\frac{2Kk'^{\frac{1}{2}}}{\pi} = 1 + 4\sum(-1)^n \frac{q^{2(2n-1)}}{1+q^{2(2n-1)}}. \tag{81}$$

Put $x = 0$ in (59) or $x = K$ in (66) and we get

$$\frac{4K^2k'}{\pi^2} = 1 + 8\sum(-1)^n \frac{nq^{2n}}{1+q^{2n}}. \tag{82}$$

With $x = 0$ or $x = K$ in (66) we find

$$\frac{K(1-k')}{4\pi} = \sum \frac{q^{2n-1}}{1+q^{2(2n-1)}}. \tag{83}$$

Compare (68).
Finally, $x = K/2$ in (67) gives (68) again.

8. In the transformation (1) that gives the two circles representing the infinite cylinders u and v remain finite in the whole of the z-plane external to the circles. Let us put w/ϵ for w, where ϵ approaches infinity. Let f approach zero so that the product ϵf approaches unity as a limit. Then (1) goes over into

$$z = \frac{2i}{w}.$$

This is the transformation used in the first part of I to solve the problem of two cylinders in contact. For equal cylinders

at a distance in a field along the line of centres the potential is expressed by the infinite series (8). In this expression write for u, v and α, u/ϵ, v/ϵ, and α/ϵ, and let ϵ approach infinity and f approach zero. Then we shall have

$$\varphi = \frac{2vF}{u^2 + v^2} - 2F\sum e^{-n\alpha/\epsilon} \frac{\sinh(nv/\epsilon)\cos(nu/\epsilon)}{\sinh(n\alpha/\epsilon)}.$$

Put $n/\epsilon = s$. Increasing n by unity increases s by $ds = 1/\epsilon$. So $\epsilon ds = 1$. The infinite sum now becomes an infinite integral and we can write

$$\varphi = \frac{2vF}{u^2 + v^2} - 2F\int_0^\infty e^{-\alpha s}\frac{\sinh vs \cos us}{\sinh \alpha s}ds.$$

Since $\varphi = 0$ when $v = \pm\alpha$, we get

$$\frac{\alpha}{\alpha^2 + u^2} = \int_0^\infty e^{-\alpha s}\cos us\, ds, \tag{84}$$

a known result. This may of course be obtained from (4) by proceeding to the limit in the same way.

We find from (9) in the same way

$$\psi = \frac{2uF}{u^2 + v^2} + 2F\int_0^\infty e^{-\alpha s}\frac{\cosh vs \sin us}{\sinh \alpha s}ds.$$

When the two equal cylinders are in a field perpendicular to the line of centres, (17) and (18) become in the limit for cylinders in contact

$$\varphi = \frac{2Fu}{u^2 + v^2} - 2F\int_0^\infty e^{-\alpha s}\frac{\cosh vs \sin us}{\cosh \alpha s}ds,$$

and

$$\psi = -\frac{2Fv}{u^2 + v^2} - 2F\int_0^\infty e^{-\alpha s}\frac{\sinh vs \sin us}{\cosh \alpha s}ds.$$

Since $\varphi = 0$ when $v = \pm\alpha$ we find

$$\frac{u}{\alpha^2 + u^2} = \int_0^\infty e^{-\alpha s}\sin us\cdot ds, \tag{85}$$

a known result that may be derived directly from (14).

The complex potential for two cylinders in contact in a field along the line of centres was given in I (19). For equal

cylinders this may be written

$$\chi = \pi a F \left\{ \frac{\sin 4mv + i \sinh 4mu}{\cosh 4mu - \cos 4mv} \right\},$$

where

$$4m = \pi a = \pi/\alpha.$$

Equating the two values of φ and ψ we therefore have

$$\int_0^\infty e^{-\alpha s} \frac{\sinh vs}{\sinh \alpha s} \cos us \, ds = \frac{v}{u^2 + v^2} - \frac{\pi}{2\alpha} \frac{\sin \frac{\pi v}{\alpha}}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}}, \quad (86)$$

and

$$\int_0^\infty e^{-\alpha s} \frac{\cosh vs}{\sinh \alpha s} \sin us \, ds$$

$$= -\frac{u}{u^2 + v^2} + \frac{\pi}{2\alpha} \frac{\sinh \frac{\pi u}{\alpha}}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}}. \quad (87)$$

For two equal cylinders in contact in a field perpendicular to the line of centres the complex potential, derived from I, Art. 6, is given by

$$\chi = \frac{2\pi F}{\alpha} \frac{\sinh 2mu \cos 2mv - i \cosh 2mu \sin 2mv}{\cosh 4mu - \cos 4mv}.$$

We therefore find

$$\int_0^\infty e^{-\alpha s} \frac{\cosh vs}{\cosh \alpha s} \sin us \, ds$$

$$= \frac{u}{u^2 + v^2} - \frac{\pi}{\alpha} \frac{\sinh \frac{\pi u}{2\alpha} \cos \frac{\pi v}{2\alpha}}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}}, \quad (88)$$

and

$$\int_0^\infty e^{-\alpha s} \frac{\sinh vs}{\cosh \alpha s} \cos us \, ds$$

$$= -\frac{v}{u^2 + v^2} + \frac{\pi}{\alpha} \frac{\cosh \frac{\pi u}{2\alpha} \sin \frac{\pi v}{2\alpha}}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}}. \quad (89)$$

These four definite integrals must be valid for

$$\alpha > 0; \ -\alpha \leq v \leq \alpha; \ -\pi \leq u \leq \pi.$$

From each of them another may be derived by making use of the reciprocal property of the Fourier integral. Applied to the integrals (84) and (85) this property yields

$$\frac{2}{\pi}\int_0^\infty \frac{\alpha}{\alpha^2 + u^2}\cos su\, du = e^{-\alpha s}, \tag{90}$$

and

$$\frac{2}{\pi}\int_0^\infty \frac{u}{\alpha^2 + u^2}\sin su\, du = e^{-\alpha s}. \tag{91}$$

Applied to the integrals (86)–(89) we get

$$\int_0^\infty \frac{\cos su\, du}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}} = \frac{\alpha \sinh (\alpha - v)s}{\sin \frac{\pi v}{\alpha} \sinh \alpha s}, \tag{92}$$

$$\int_0^\infty \frac{\sinh \frac{\pi u}{\alpha} \sin su \cdot du}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}} = \frac{\alpha \cosh (\alpha - v)s}{\sinh \alpha s}, \tag{93}$$

$$\int_0^\infty \frac{\sinh \frac{\pi u}{2\alpha} \sin su\, du}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}} = \frac{\alpha}{2}\frac{\sinh (\alpha - v)s}{\cosh \alpha s \cos \frac{\pi v}{2\alpha}}, \tag{94}$$

and

$$\int_0^\infty \frac{\cosh \frac{\pi u}{2\alpha} \cos su\, du}{\cosh \frac{\pi u}{\alpha} - \cos \frac{\pi v}{\alpha}} = \frac{\alpha}{2}\frac{\cosh (\alpha - v)s}{\cosh \alpha s \sin \frac{\pi v}{2\alpha}}. \tag{95}$$

When the reciprocal property of the Fourier integral is again applied to the last four integrals we of course recover the integrals (86)–(89) although expressed in a different form; these may also be derived by making use of the two integrals (84) and (85). We therefore find, putting $\alpha - v = \beta$,

$$\int_0^\infty \frac{\sinh \beta s \cos us}{\sinh \alpha s} ds = \frac{\pi}{2\alpha} \frac{\sin \frac{\pi\beta}{\alpha}}{\cosh \frac{\pi u}{\alpha} + \cos \frac{\pi\beta}{\alpha}}, \tag{96}$$

$$\int_0^\infty \frac{\cosh \beta s \sin us}{\sinh \alpha s} ds = \frac{\pi}{2\alpha} \frac{\sinh \frac{\pi u}{\alpha}}{\cosh \frac{\pi u}{\alpha} + \cos \frac{\pi\beta}{\alpha}}, \tag{97}$$

$$\int_0^\infty \frac{\sinh \beta s \sin us}{\cosh \alpha s} ds = \frac{\pi}{\alpha} \frac{\sinh \frac{\pi u}{2\alpha} \sin \frac{\pi\beta}{2\alpha}}{\cosh \frac{\pi u}{\alpha} + \cos \frac{\pi\beta}{\alpha}}, \tag{98}$$

and

$$\int_0^\infty \frac{\cosh \beta s \cos us}{\cosh \alpha s} ds = \frac{\pi}{\alpha} \frac{\cosh \frac{\pi u}{2\alpha} \cos \frac{\pi\beta}{2\alpha}}{\cosh \frac{\pi u}{\alpha} + \cos \frac{\pi\beta}{\alpha}}. \tag{99}$$

By giving special values to the variables that enter into these twelve integrals many simpler definite integrals, usually determined by the method of contour integration, may be evaluated. For example, putting $u = 0$ in (96), we find

$$\int_0^\infty \frac{\sinh \beta s}{\sinh \alpha s} ds = \frac{\pi}{2\alpha} \tan \frac{\pi\beta}{2\alpha}. \tag{100}$$

The same substitution in (99) gives

$$\int_0^\infty \frac{\cosh \beta s}{\cosh \alpha s} ds = \frac{\pi}{2\alpha} \sec \frac{\pi\beta}{2\alpha}. \tag{101}$$

$\beta = 0$ in (97) gives

$$\int_0^\infty \frac{\sin us}{\sinh \alpha s} ds = \frac{\pi}{2\alpha} \tanh \frac{\pi u}{2\alpha}. \tag{102}$$

Another application of these integrals is to the development of circular and hyperbolic functions in partial fractions. In (86) we can expand

$$e^{-\alpha s} \frac{\sinh \varepsilon s}{\sinh \alpha s} = \sum_1^\infty e^{-(2n\alpha - \varepsilon)s} - \sum_1^\infty e^{-(2n\alpha + \varepsilon)s}.$$

Carrying out the integration term by term with the aid of (84), we get

$$\sum \frac{2n\alpha - v}{(2n\alpha - v)^2 + u^2} - \sum \frac{2n\alpha + v}{(2n\alpha + v)^2 + u^2}$$

$$= \frac{v}{u^2 + v^2} - \frac{\pi}{2\alpha} \frac{\sin \dfrac{\pi v}{\alpha}}{\cosh \dfrac{\pi u}{\alpha} - \cos \dfrac{\pi v}{\alpha}}.$$

Writing $\pi u/\alpha = x$, $\pi v/\alpha = y$, we derive

$$\frac{\sin y}{\cosh x - \cos y} = 2 \sum_{-\infty}^{+\infty} \frac{2n\pi + y}{(2n\pi + y)^2 + x^2}, \tag{103}$$

where the summation is for all positive and negative integers including zero. If we put $x = 0$ in this we get

$$x \cot x = 1 - 2 \sum_{1}^{\infty} \frac{x^2}{(n\pi)^2 - x^2}.$$

From (87) we find in the same way

$$\frac{\sinh x}{\cosh x - \cos y} = 2 \sum_{-\infty}^{+\infty} \frac{x}{(2n\pi + y)^2 + x^2}. \tag{104}$$

For $y = \pi/2$, this gives

$$x \tanh x = 2 \sum_{1}^{\infty} \frac{x^2}{\left(\dfrac{2n - 1}{2}\pi\right)^2 - x^2}.$$

From (88) follows

$$\frac{\sinh \dfrac{x}{2} \cos \dfrac{y}{2}}{\cosh x - \cos y} = \sum_{-\infty}^{+\infty} (-1)^n \frac{x}{(2n\pi - y)^2 + x^2}, \tag{105}$$

and with $y = 0$ we get

$$x \operatorname{csch} x = 1 + 2 \sum (-1)^n \frac{x^2}{(n\pi)^2 + x^2}.$$

From (89) we derive

$$\frac{\cosh \dfrac{x}{2} \sin \dfrac{y}{2}}{\cosh x - \cos y} = \sum_{-\infty}^{+\infty} (-1)^n \frac{2n\pi + y}{(2n\pi + y)^2 + x^2}. \tag{106}$$

$y = \pi$ gives

$$\operatorname{sech} x = 4\pi \sum_{1}^{\infty} (-1)^{n+1} \frac{2n - 1}{(2n - 1)^2\pi^2 + 4x^2}.$$

FOSSIL TURTLES FROM MARYLAND *

R. LEE COLLINS AND W. GARDNER LYNN

Abstract

A number of fossil turtles have been found in Maryland in beds that range in age from Cretaceous to Pleistocene. Most of the early records are based on fragmentary material, some of which was never figured and has since been lost. This paper gives a very brief résumé of the published records and discusses at some length remains of *Taphrosphys miocenica* n. sp., *Chelonia marylandica* n. sp. and *Testudo ducateli* n. sp. which were collected in 1934 and 1935 from the Miocene, Calvert formation in Calvert County. The genus *Taphrosphys* formerly included remains known only from the upper Cretaceous of New Jersey and Georgia or North Carolina. This genus is placed in the superfamily Pleurodira or side-neck turtles, a group in which the neck can not be retracted in a vertical sigmoid curve between the scapulae, but is bent laterally. Heretofore, pleurodirid turtles were not known from the North American continent after the upper Cretaceous and the recent species are confined almost entirely to the southern hemisphere. *Testudo* occurs in the upper Eocene, Uinta formation of the Western United States, is well represented in the Oligocene and Miocene of the same region and is present in Pliocene and Pleistocene deposits in the southern and southeastern part of the country. It is now evident that *Testudo* was present in eastern North America and ranged as far north as Maryland during the Miocene and that pleurodirid turtles lived in the same region throughout a part of the Tertiary period. Chelonian remains in the Calvert beds may serve as corroborative evidence that climatic conditions were much more mild in the Maryland region during the Miocene than at the present time.

Résumé of Older Records

A number of fossil turtles have been found in the State of Maryland, where they are known to occur in beds that range in age from lower Cretaceous to Pleistocene. Some seven

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genera have been mentioned in the past, but most of the older records describe fragmentary and very meagre material, some of which was never figured and has since been lost. Early papers describing these remains are reviewed briefly in the following paragraphs and the more important contributions, those with good descriptions and figures, are cited.

The first notice of turtle remains from the state was published by Cope[1] in 1867. This paper describes *Trionyx cellulosus* Cope, *Trionyx* species and remains of two unnamed species of *Chelone*. The material consisted of carapace fragments which were collected in Charles County near the Patuxent River from beds of the "Yorktown epoch," now known as the Calvert formation. The proximal part of a scapula from the Calvert formation at Plum Point, Calvert County, was described by Case[2] and referred to the genus *Chelone*. Hay[3] regarded this specimen and those assigned to *Chelone* by Cope, as generically indeterminable, but included them under his discussion of the genus *Chelonia*. He also stated that Cope reported a costal of *Chelonia ? parvitecta* Cope from Charles County, Maryland. The *Trionyx* remains described by Cope are included questionably under the genus *Amyda* by Hay.[4] Cope's specimens were originally in the collections of the Philadelphia Academy, were never figured and appear to be lost.[5]

These *Trionyx* specimens may have been fragments of crocodilian dermal scutes somewhat similar to undescribed material which the authors have collected from Zone 12, near the top of the Calvert formation, just south of the mouth of Parker Creek and from Zone 19, Choptank formation at Point of Rocks, Calvert County. The fact that Cope made special comment on the scoria-like appearance of the surface

[1] E. D. Cope. "An Addition to the Vertebrate Fauna of the Miocene Period, etc.," *Proc. Acad. Nat. Sci., Phila.*, 19. pp. 142, 1867.

[2] E. C. Case. Maryland Geol Surv, Miocene report, p. 64, Atlas, pl. 26, fig. 6, 1904.

[3] O. P. Hay. "The Fossil Turtles of North America," *Carnegie Inst. Washington*, No. 75, p. 220, 1908.

[4] O. P. Hay, op. cit., 1908, p. 534.

[5] O. P. Hay, idem., 1908, p. 534.

of the *Trionyx* remains, the unusual depth of the pits and the round-edged septa between them, suggests very strongly this undescribed crocodilian material. However, Cope's statement that the "width of free portion of rib at origin" is "7.5 lines," indicates a chelonian costal plate, if the fragment was correctly determined.

Chelydra serpentina Linnaeus and *Cistudo eurypygia* were reported by Cope [1] in 1869. These remains were found along with bones of *Elephas primigenius, Cervus canadensis* and *Odocoileus virginianus* by Dr. Samuel R. Harrison of Easton, in Pleistocene deposits at Oxford Neck, Talbot County. Cope did not state what parts of *Chelydra serpentina* were found and according to Hay,[2] the specimens have been lost. Hay [3] gives a very good discussion of *Terrapene eurypygia* (Cope) in his monograph on the fossil turtles of North America. This species also occurs in the Pleistocene, Port Kennedy cave deposits in Pennsylvania where more complete material has been found.

Dr. W. B. Clark recorded fragments of a large carapace from the Eocene, Aquia formation at Clifton Beach, Charles County. These fragments were referred questionably to the genus *Euclastes*. Later, Case [4] repeated Clark's description and figured one fragment. Hay [5] assigned this material questionably to Cope's genus *Lytoloma* and stated that the materials were generically indeterminable.

Fragmentary turtle remains were collected by J. B. Hatcher in 1887, at Muirkirk, Prince George's County from the lower Cretaceous, Arundel formation. These remains were studied and described by Hay [6] under the name of *Glyptops caelatus*.

[1] E. D. Cope. "Extinct Batrachia, Reptilia and Aves of North America," *Trans. Amer. Phil. Soc.*, 14, p. 125, 1871.

[2] O. P. Hay. Maryland Geol. Surv. Pliocene and Pleistocene report, p. 170, 1906.

[3] O. P. Hay, op. cit., 1908, pp. 364, fig. 466. Type material, rear of carapace, Amer. Mus. Nat. Hist., New York, No. 1484.

[4] E. C. Case. Maryland Geol. Surv. Eocene report, p. 97, pl. 10, fig. 7, 1901.

[5] O. P. Hay, op. cit., 1908, pp. 154.

[6] O. P. Hay, op. cit., 1908, pp. 52–3, text-figs. 28–31, pl. 7, figs. 1–2. Type, U. S. Nat. Mus., No. 1930, other material No. 1939.

In 1909 Palmer [1] described and figured part of the remains of a new species of leatherback turtle, *Psephophorus calvertensis*, which he collected from the Calvert formation two miles south of Chesapeake Beach, Calvert County, at an elevation about thirty feet above beach level. This specimen appears to have been found in Zone 10 of the Calvert formation, as defined in the Maryland Geological Survey Miocene report.[2] The authors have found a few scattered plates that seem to be those of *P. calvertensis* in Zone 10 and on the beach, at a point about one mile south of Chesapeake Beach.

The list of turtle remains from Maryland, including the material collected in 1934 and 1935, now contains some nine genera representing nine families. Of this number, one is known from the lower Cretaceous, one from the Eocene, five from the Miocene and two from the Pleistocene. This disparity does not necessarily indicate that turtles were less abundant in the region during other epochs than the Miocene, but is attributable in part to conditions of exposure of the various beds. Fossiliferous outcrops of the lower Cretaceous, Eocene and Pleistocene are rather limited in extent and often highly weathered in contrast to the great extent and excellence of the Miocene exposures along the western shore of the Chesapeake Bay.

The terminology in the following systematic list conforms with that given in Hay in 1930.[3]

SYSTEMATIC LIST OF FOSSIL TURTLES FROM MARYLAND

Family DERMOCHELYIDAE

Psephophorus calvertensis Palmer.........Zone 10, Calvert formation, Miocene.

Family PLEUROSTERNIDAE

Glyptops caelatus Hay...................Arundel formation, lower Cretaceous.

Family BOTHREMYDIDAE

Taphrosphys miocenica n. sp..............Zone 10, Calvert formation, Miocene.

Family THALASSEMYDIDAE

Lytoloma ? sp...................................Aquia formation, Eocene.

[1] Wm. Palmer. "Description of a New Species of Leatherback Turtle from the Miocene of Maryland," *Proc. U. S. Nat. Mus.*, pp. 369–373, pl. 31, April. 1909. Type, U. S. Nat. Mus, No. 6059.

[2] P. lxxvi, see pl. v, sections iii and iv, 1904.

[3] O. P. Hay. "Second Bibliography and Catalogue of the Fossil Vertebrata of North America," *Carnegie Inst., Washington*, No 390, ii, pp. 64–113, Jan. 27, 1930.

Family CHELONIIDAE
Chelonia ? parvitecta (Cope)........ . . ..Calvert formation, Miocene.
Chelonia marylandica n. sp...............Zone 10, Calvert formation, Miocene.
Family CHELYDRIDAE
Chelydra serpentina (Linnaeus).......... . ...Pleistocene, early or middle.
Family EMYDIDAE
Terrapene eurypygia (Cope).......................Pleistocene, early or middle.
Family TESTUDINIDAE
Testudo ducateli n. sp....... ....Zone 10, Calvert formation, Miocene.
Family TRYONYCHIDAE
Amyda ? cellulosa (Cope)........................Calvert formation, Miocene.
Amyda ? sp....... .. ..Calvert formation, Miocene.

Records of *Amyda* and *Lytoloma* require additional evidence before they can be accepted without question and the Pleistocene remains of *Chelydra serpentina* are no longer available, but the occurrence of the remaining forms seems to be substantiated by adequate material.

Taphrosphys miocenica Collins and Lynn, n. sp.

Plate I

Type.—Catalogue No. 13784, Division of Vertebrate Paleontology, United States National Museum. The specimen upon which this species is based, consists of the anterior portion of a plastron composed of five complete bones, the paired epiplastra and hyoplastra and the entoplastron.

Type Locality.—The material was collected in April 1934, from the Calvert Cliffs, about one-fourth of a mile south of Camp Roosevelt, Maryland, in Zone 10 of the Calvert formation which here lies about 30 feet above high tide level.

The specimen is well preserved and the epidermal sulci as well as the sutures are clearly traceable. It measures 222 mm. in length along the midline and 360 mm. in width across the bridge. The anterior lobe of this plastron is short, broad and rounded and there are well developed but rather thin axillary buttresses. The thickness of the bones varies from about 4 mm. at their centers to about 10 mm. at the edges. At the symphysis of the epiplastra, however, an abrupt internal ridge increases the thickness to 15 mm. (Pl. I). The sutures between the bones are characterized by prominent peg and

socket articulations. There is no indication of sculpturing on the outer surface.

The form and proportions of the various bones are shown in Pl. I which may be supplemented by the following measurements. The epiplastra are 30 mm. wide at the symphysis increasing to 42 mm. at the epihyoplastral suture; their length is 80 mm. On the left side a small accessory bone is inserted between epi- and hyoplastron at the outer edge. The entoplastron is broader than long, being 73 mm. in length at the midline and 92 mm. at its greatest width. The right hyoplastron is 102 mm. long at the midline, the left 118 mm.; each is 180 mm. wide. Just behind the axillary buttress the posterior border of each hyoplastron turns sharply forward. It appears evident that this is for the reception of small triangular mesoplastral bones situated on the bridges of the plastron. This hyomesoplastral suture measures 70 mm. in extent on the right side while the hyohypoplastral suture is 125 mm. long.

The sulci marking the boundaries of the epidermal scutes are shallow, but easily discernible and the arrangement of these scutes is also shown in Pl. I. There was a single intergular located partly on the entoplastron but mostly on the epiplastra and completely separating the two gulars; it was 42 mm. in length and 33 mm. at its greatest width. The gular scutes were confined entirely to the epiplastra and were small; the right gular measuring 25 mm. along the intergulo-gular sulcus and 28 mm. at its greatest width. The humerals were relatively small, the humero-pectoral sulcus running almost entirely on the entoplastron and epiplastra and striking the hyoplastron only at the outer edge on the right side. The measurements for the right humeral are: inter-humeral sulcus, 12 mm.; intergulo-humeral sulcus, 20 mm.; gulo-humeral sulcus, 32 mm.; humero-pectoral sulcus, 90 mm.; free border, 60 mm. The pectoral scutes were large, the inter-pectoral sulcus being 101 mm. long, the right pectoro-abdominal sulcus 172 mm. The latter crosses the hyoplastron at about 50 mm. from the hyohypoplastral suture. A portion of a single

marginal scute overlapped the hyoplastron at the bridge. There were no axillary or inframarginal scutes.

Taphrosphys is a genus of fossil turtles belonging to the superfamily Pleurodira, the snake-necked or side-necked turtles. Living pleurodires fall into three families, Pelomedusidae, Chelydidae and Carettochelydidae, the members of which are confined almost entirely to the torrid and south temperate zones. *Taphrosphys* appears to be most closely related to the Pelomedusidae, and was originally assigned to that family by Cope.[1] Baur,[2] however, regards it as falling into a separate family, the Bothremydidae, and this classification is accepted by Hay.[3]

In North America, the earliest known fossil representatives of the Pleurodira occur in the upper Cretaceous and heretofore none were known from any deposits of later age. There is thus a great gap in time between the previously known members of the group and the present specimen and it is necessary to examine closely the reasons for assigning this specimen to that group. Hay's diagnosis of the genus *Taphrosphys* in so far as it relates to the plastron is as follows:

"A genus of pleurodirid turtles known only from the shell. . . . Plastron with 11 bones, the mesoplastrals small and well out on the bridges. A single intergular almost wholly confined to the entoplastron. Hinder lobe with large notch. . . . Ischium and pubis articulated to the xiphiplastron. . . . The plastron was well developt, but the anterior lobe was short and broad, and rounded. Strong buttresses rose from the plastron to articulate with the carapace. On the xiphiplastrals were well-developt articulatory surfaces for union with the ischia and the pubes. The posterior notch was large and rounded. As stated by Cope, and as shown by the borders of various hyoplastra and hypoplastra, there were small triangular mesoplastra, which occupied each a position on its bridge. The free borders of the anterior lobe were mostly obtuse; those of the hinder lobe were mostly acute. The inferior surface is sculptured like the carapace; but often the markings are obscure. The scutes of the anterior lobe are not all satisfactorily determined.

[1] E. D. Cope. Cook's Geol. of N. J. 1868 (1869), p. 735.
[2] G. Baur, *Ann. and Mag. Nat. Hist.* (6). IV, 1889, p. 38.
[3] O. P. Hay, op. cit., 1908, p. 102.

There was a large intergular that occupied a considerable portion of the entoplastron. Apparently, . . . this was bounded in front by a sulcus across the entoplastron thus permitting the gulars to meet each other at the midline. It is possible that the intergular extends to the front of the lobe, . . . and that the gulars do not join each other. The humerals lie on the outer ends of the epiplastra, overlapping on the hyoplastra. . . . Those on the bridges are not known."

It will be seen that the present specimen shows a rather close general agreement with Hay's description. In detail the reasons for association of this specimen with the Pleurodira and with *Taphrosphys* in particular are as follows: (1) The existence of small mesoplastral bones on the bridge. Although these bones are not actually present their existence seems to be very definitely indicated. Mesoplastra are found only in turtles belonging to the superfamilies Amphichelydia and Pleurodira and in the former group these bones usually meet in the midline or approach it very closely; only in the Pleurodira may they be set so far out on the bridges of the plastron. (2) The presence of an unpaired intergular scute separating the gulars. In the Amphichelydia the intergulars are paired and they fail to separate the gulars completely. Certain members of the superfamily Cryptodira, *Basilemys*, *Adocus* and *Alamosemys*, possess intergulars which separate the gulars, but in these also there is a pair of intergulars rather than a single one. Aside from this however, the existence of mesoplastra definitely removes this specimen from the Cryptodira. (3) The absence of axillary and inframarginal scutes on the hyoplastron. In this the specimen differs from the Amphichelydia and also from the genera mentioned above, *Basilemys*, etc. Since the scutes of this region are not known in previously described specimens of *Taphrosphys* it is uncertain whether this is a characteristic common to all members of the genus. However the absence of these scutes is a feature of the plastron of many of the present-day pleurodires, *Podocnemis*, *Sternothaerus*, *Pelomedusa* and *Hydromedusa*. (4) The small size of the humeral scutes. This reduction of the humerals to the point at which the humero-pectoral

sulcus lies entirely above the posterior border of the entoplastron seems a character which is almost wholly confined to the Pleurodira. Certain of the Cryptodira, *Xenochelys*, *Echmatemys* and *Terrapene*, exhibit this condition but in none of these is there an intergular present. (5) General form and dimensions. The broad rounded anterior lobe of this plastron differs greatly from that of most forms and agrees strikingly with those of other Pleurodires, and the size of the specimen is of the same order as that of the described species of *Taphrosphys*.

Six of the seven described species of *Taphrosphys* are from the upper Cretaceous greensands of New Jersey and one is from the upper Cretaceous of Georgia or North Carolina. In as much as they are all based on fragmentary material, the present specimen serves to fill in some of the gaps in our knowledge of the genus. This is true especially with relation to the arrangement of the epidermal scutes of the anterior lobe of the plastron. In the Miocene specimen it is clear that the single intergular is continued to the anterior border of the plastron and thus completely separates the gulars. Hay, in his examination of the other species, was not able to clear up this point, but was inclined to believe that the intergular was confined to the entoplastron and that the gulars met in front of it. This opinion is based upon the entoplastron of *T. molops* in which he distinguished a sulcus bounding the anterior border of the intergular. However, Cope [1] in his description of the same specimen failed to see such a sulcus and considered that the intergular extended on to the epiplastra. Only one other specimen, a portion of the plastron of *T. leslianus* gives any information on this point and here the relations appear to be as in *T. miocenica* though the incompleteness of the specimen leaves the question in doubt. In present day pleurodires the intergular is usually terminal, but in one genus, *Chelodina*, it is shut in behind the gulars. The bridges of the plastron are absent in all previously described fossil species and the absence of axillary and infra-

[1] E. D. Cope, op. cit., 1871, p. 158.

marginal scutes in these regions is therefore worthy of note. The portion of a single scute which is found on the extreme edge of the hyoplastron is interpreted as a marginal.

The turtles belonging to the superfamily Pleurodira are in some respects the most specialized of all chelonians. Hay believes them to have originated from a primitive amphichelydian stock, possibly during the Triassic. Although Gadow [1] states that the oldest pleurodiran fossils occur in the Jurassic, accepting *Plesiochelys* of Switzerland as a true pleurodire, Hay regards this form as an amphichelydian and considers *Pleurosternon* of the upper Cretaceous of Provence, France and *Taphrosphys* of the upper Cretaceous of North America as the earliest known representatives of the group. The importance of the present specimen in greatly extending the geological record of the group in the North American continent has already been pointed out. Hay calls special attention to the fact that, judging by our previous knowledge, the pleurodires in North America both arose and disappeared in the Cretaceous; thus dying off even before the Amphichelydia, the stock from which they had originated. It is now apparent that such was not the case. The last of the Amphichelydia recorded from North America are species from the Uinta and Bridger formations, Eocene deposits of the west, but the pleurodires persisted into the Miocene and possibly later. Similarly, during the same periods, the group inhabited Europe, as evidenced by a number of fossil forms from the upper Cretaceous and Eocene of England and the continent. The reason for the disappearance of these turtles from the northern portions of the world is obscure, but may be related in part to glaciation of these regions during the Pleistocene. Attention has also been called to the fact that existent pleurodires are confined almost entirely to the southern hemisphere. They are found in South America, Africa, Madagascar, an isolated species at the head of the Red Sea and in Australia and New Guinea.

The wide-spread geographical distribution of the existent

[1] H. Gadow. *Amphibia and Reptiles*. MacMillan and Company, p. 389, 1901.

pleurodires is not surprising in view of the long geological history of the group, but considerable interest attaches to their distribution because of the habits of these animals. They are exclusively fresh-water forms and are apparently never found in salt or even brackish water. (For an excellent discussion of the habits and habitats of recent pleurodires the reader is referred to Gadow.[1]) It is obvious that the occurrence of closely related pleurodires in land-masses now widely separated by water gives at least a strong presumption of the existence of former land connections of sufficient permanency to develop well-defined river systems. Thus, the presence of closely related species belonging to this group in Madagascar and in South America has been adduced as additional evidence for the postulated land bridge between South America and Africa during the Mesozoic. In the same way the occurrence of members of the fossil genus *Miolania*, a peculiar group with horn-like processes on the back of the head, found in Pleistocene deposits on Lord Howe Island, in Queensland, Australia, and in earlier deposits in Patagonia, seems to indicate a former land connection between Australia and South America.

The lack of specimens from deposits intermediate in age between the Cretaceous and Miocene and the apparent rarity of specimens in the Miocene itself, may be susceptible to at least partial explanation. Despite the fact that all the New Jersey specimens of *Taphrosphys* are usually considered to be from the upper Cretaceous, in reality, considerable uncertainty exists regarding the exact horizons from which the remains were collected. In view of the confusion which formerly existed relative to the boundary between upper Cretaceous and Eocene deposits in the region and the very recent elucidation of the problem by Cooke and Stephenson,[2] it is highly probable that some of the *Taphrosphys* material may have come from the Tertiary. The seeming abundance of these remains in the Jersey section may be real, or on the

[1] H. Gadow, op. cit., 1901. pp. 388–404.

[2] C. Wythe Cooke and Lloyd W. Stephenson. "The Eocene Age of the Supposed Late Upper Cretaceous of New Jersey," *Journ. Geol.*, 36, pp. 139–148. 1928.

other hand, merely simulated, the result of extensive exposures developed in the old greensand marl workings. It is also uncertain whether the specimens were found in typical marine sediments or in horizons that suggest brackish or even fresh water deposits. A reasonable assumption would be that the fossil forms occupied fresh water habitats like the pleurodires in the recent fauna and that we would therefore not expect to find them normally in marine beds. Fresh water and land animals are sometimes carried out to sea by rivers; their bones are not uncommon along recent coastal beaches and they occur sporadically as fossils in marine deposits. The fossils in the Calvert beds, much cetacean material in addition to an abundance of marine invertebrates, indicate that many of the zones recognized in the Miocene beds along the western margin of the Chesapeake Bay represent coastal or open sea conditions. Therefore, it is believed that *T. miocenica*, at least, was a fresh water turtle and that the rarity of pleurodiran remains in the Tertiary is largely the result of conditions of sedimentation.

Chelonia marylandica, Collins and Lynn, n. sp.

Plate II, Text-figure 1

Type.—Catalogue No. 13825, Division of Vertebrate Paleontology, United States National Museum. This species is based on a portion of the carapace consisting of the second, third and fourth neurals, the second, third and fourth costals of both right and left sides together with the fourth and fifth peripherals of the right side and the fourth to sixth of the left.

Type Locality.—These remains were collected from a locality approximately 2.3 miles south of Chesapeake Beach, Maryland on July 1, 1935.

Horizon.—This specimen was found at the base of Zone 10 of the Calvert formation.

The specimen is a sea-turtle belonging to the family Cheloniidae and shows considerable similarity to the recent genus *Chelonia*. It is provisionally referred to this group

although it is probable that more complete remains would justify the erection of a new genus for its reception. Plate II is a photograph of the specimen with the peripherals in their approximate positions and the course of the epidermal sulci marked on the bones. The external surfaces of all these bones exhibit vascular grooves which tend to run parallel to the intercostal sutures on the distal two-thirds of the costal bones, but on the proximal third form distinct pits with grooves running at right angles to the long axis of the plate. The neurals show only a few pits in the bones and some grooves at the anterior ends. A notable feature of this carapace is the presence of prominent dorsal and lateral keels which appear clearly in the photograph. The lateral keels seem to diminish somewhat posteriorly. The measurements of all the bones which are sufficiently complete to make accurate measurement possible are given in the following table (in millimeters)

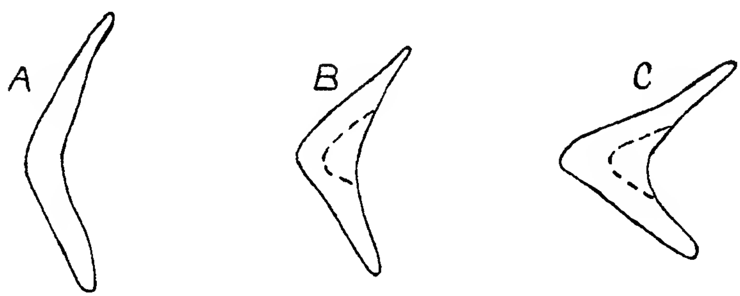
	Length	Width
Neural 2	35	26
Neural 3	49	34
Neural 4		35
R. Costal 2	114	50
R. Costal 3	113	48
L. Costal 2	114	52
L. Costal 3	112	47
L. Costal 4	100	42
R. Peripheral 4	46	
L. Peripheral 4	46	24
L. Peripheral 5	47	
L. Peripheral 6		34

The above lengths are taken along the midline for the neurals and through the centers of the costals. The widths of the neurals are taken at the widest point, widths of the costals are taken at the middle. The lengths given for the costals are taken only to the border of the bones and not onto the projecting rib ends. The rib ends of only the second and third costals of the left side are complete. These project 27 and 29 mm. respectively beyond the border of the costals. They fit into deep conical pits in the posterior parts of the fourth and fifth peripheral and when placed in position as they

are in the figure it is clear that costoperipheral fontanelles varying from 5 to 15 mm. in width were present in this turtle.

The peripheral bones exhibit well-defined markings and their free borders become increasingly acute towards the middle of the carapace as may be seen from the sections (Fig. 1). The costal edges of these bones are thin, while the plastral edges are thick and rounded.

The small size and octagonal shape of the second neural in this turtle is a feature worthy of note and as a result of it, the second costal abuts three neural bones instead of two as is usually the case. It is probable that the first neural had the



TEXT-FIG. 1. Cross-sectional outlines of peripheral plates of *Chelonia marylandica*, × 1. *A*. Section at anterior end of fourth left peripheral. *B*. Section at posterior end of fourth left peripheral. *C*. Section at center of fifth left peripheral. Outlines of the pits for reception of the rib ends are shown by the broken lines.

broader end behind. Such a condition seems to be extremely rare among turtles but is found in several other members of the Cheloniidae, notably those belonging to the fossil genus *Procolpochelys*. It may possibly indicate that there were more than the usual eight neurals in this form.

As already stated, the exact relations of this turtle are somewhat uncertain. There is little doubt that it belongs to the family Cheloniidae, a group of purely marine turtles which at the present day are found in all tropical and subtropical seas. However, it is unlikely that it is congeneric with the recent Green Turtle *Chelonia mydas* (Linnaeus). It is referred to that genus because it is obviously a closely related form and because the authors hesitate to erect a new genus on the

basis of so fragmentary a specimen. A similar situation exists with regard to another fossil turtle which was originally described under the name *Puppigerus parvitecta* by Cope. It is represented by a single fragmentary costal from the Eocene at Squankum, Monmouth County, New Jersey. Cope reported finding another costal in Charles County, Maryland, but this specimen seems to have been lost. Hay has found it necessary to remove this turtle from the genus *Puppigerus* and has assigned it, with some question, to the genus *Chelonia*. The type costal of *Chelonia ? parvitecta* resembles those of the turtle here described but clearly represents a different species. The most important dissimilarities are the absence of lateral keels in *Chelonia ? parvitecta* and the difference in shape of the vertebral scutes in the two. It is probable that these two turtles are species belonging to a genus which, as Hay points out, is yet to be established but is closely related to the present-day *Chelonia*.

Fragments of the carapace of still another member of the Cheloniidae are rather frequently met with in the Miocene of Maryland and have been collected *in situ* from Zones 10, 11 and 12 of the Calvert formation. These bones clearly pertain to a turtle closely related to *Chelonia* but show significant differences in the sculpturing, which consists of elongate ridges and grooves rather than vascular impressions. Such sculpturing is characteristic of the fossil sea-turtles *Peritresius* and *Syllomus*, both of which genera are at present monospecific. The former is represented by *Peritresius ornatus* (Leidy), which was first described on the basis of two peripherals from the Cretaceous of New Jersey but is also known from the Ripley formation of Georgia. The genus *Syllomus* was erected by Cope in 1896 for the reception of the species *Syllomus crispatus* Cope and is based upon a humerus and portions of two costals from Miocene deposits on the Pamunkey River, Virginia. The costals in this form were united with the peripherals by suture and this feature serves to distinguish the genus from *Peritresius* in which costo-peripheral fontanelles were present. With respect to this

characteristic the material from the Calvert agrees with *Peritresius* and may be provisionally referred to that genus. It is described in the paper which follows and is therefore not given detailed consideration at this time.

Testudo ducateli, Collins and Lynn, n. sp.

Plates III and IV

Type.—Catalogue No. 13783, Division of Vertebrate Paleontology, United States National Museum. The specimen includes the complete plastron and the second neural, second and third right costals, fourth to eighth right peripherals inclusive and the fourth left peripheral of the carapace. The individual seems to have been a male.

Type Locality.—The remains were collected by the authors on October 26, 1934, from a cut bank on the west side of the Chesapeake Beach-Plum Point road, 3.4 miles south of the old Chesapeake Beach Railroad Station. This road cut lies about one-quarter of a mile inland from the bluffs bordering the Chesapeake Bay to the east.

Horizon.—The locality has an approximate elevation of 30 feet above sea level and appears to belong to Zone 10 of the Calvert formation. The material in which the bones were found consists of yellowish, friable sand from which most of the molluscan shells have been leached by ground water and plant roots. Highly weathered fragments of two porpoise skulls were observed in this same cut and a right mandible (1625 mm. long) of a cetothere, a few fragmentary plates of an undetermined genus of turtle, numerous fish teeth and a few porpoise teeth were collected a few feet from the spot where the *Testudo* remains were found. The *Testudo* bones are somewhat worn, particularly along some of the sutures from which adjoining plates seem to have been lost at some time before their burial.

The Carapace.—The second neural is 44.0 mm. long, 49.2 mm. wide; the inner surface is considerably abraded, but the average thickness of the plate is about 4 mm. The vertebral attachment is very thin and runs the whole length of the neu-

ral. The neural is octagonal in outline and narrows slightly toward the anterior end which is broadly indented along the line of suture with the preceding neural. The lateral margins bear broader indentations at the points of attachment of the right and left second costals. The configuration of the second neural and its relations to the two right costals suggests that the first neural was probably sub-ovate in outline and in contact with only the first costal. The second neural, on the other hand, joined costals one, two and three. The third neural seems to have been joined with the third costals and to have been sub-quadrate in outline.

The second right costal is 109.0 mm. long, 42.5 mm. wide at the lower end, 27.0 mm. wide at the suture with the second neural and about 7 mm. thick at the lower margin. It tapers gently from the base toward the upper margin which is broadly rounded at the neural suture.

The third right costal is 119.5 mm. long, 44.0 mm. wide at the neural suture where it made contact with neurals two, three and four, 22.5 mm. across the suture with the third neural, 29.0 mm. wide and about 7 mm. thick at the lower margin. Both costals are thickest near the costoperipheral suture. Their visceral surfaces are badly worn, but traces of the ribs seem to indicate that the rib heads were very slender. The costals and contiguous peripherals are articulated by well developed digitating sutures.

MEASUREMENTS OF PERIPHERALS (IN MILLIMETERS)

	4 left	4 right	5 right	6 right	7 right	8 right
Length	76.0	77.0	86.0	90.0	81.0	71.0
Width at proximal end	35.5	35.2	42.0	43.5	34.0	27.0
Width at distal end	32.0	29.0	36.0	37.0	43.0	38.5
Greatest thickness	8.5	8.5	5.5	5.5	17.0	30.0

The fourth right and left peripherals are thickest at the anterior median part of the plate which seems to indicate that the anterior free margin of the carapace, in front of the axillary

notches, was somewhat expanded and slightly undulated. The posterior free margin, in back of the inguinal notches, also seems to have been somewhat flaring and undulated.

The carapace appears to have been firmly constructed and rather high and tumid. The sulci of the carapace are all well marked except the one lying between the costal and marginal scutes. This sulcus followed the costoperipheral suture, but the plates are worn in this region and little or no trace of the sulcus remains, therefore it has been indicated by the broken dotted line on figs. 4 and 5 of Pl. IV. Marginal scute eight was curved around the posterior free margin of the carapace and a rapidly tapering projection of the scute extended upward within the inner surface of the margin for a distance of 34 mm.

The Plastron.—The plastron exhibits the general characteristics common to members of the genus, a well marked anal notch, slightly projecting epiplastral lip and firm and extended articulation with the carapace. The anterior end is strongly curved upward and the dorsal surface of the epiplastral lip is almost horizontal. The ventral surface of the plastron just in front of the inguinal notches is markedly concave and the corresponding visceral surface elevated as shown in the side view, Pl. IV, fig. 3. This concave area suggests, that the individual was probably a male. A small accessory bone is present in the middle of the plastron, but accessory bones and scutes are not uncommon in turtles; furthermore, they may be expected to occur in this particular region where the yolk sack is attached to the young. A slight injury at this point may easily give rise to one or more accessory plates.

The thickness of the plastron varies greatly from one part to another as shown by the sections Pl. III and the table of measurements on page 169.

The inguinal buttresses are strongly developed, but rather slender at the point of attachment with the peripherals and extend almost at right angles to the plastral axis. The right buttress runs from the lower posterior part of peripheral seven

somewhat obliquely across peripheral eight which is very much thickened in the region of attachment and appears to have ended before reaching the upper margin of this plate. The proximal margin of peripheral eight is considerably thickened and it may be assumed that the contiguous part of costal six (?) was also thickened. The axillary buttresses are well developed and slightly oblique to the plastral axis. They probably did not reach beyond the upper margin of the fourth peripheral.

MEASUREMENTS OF THE PLASTRON (IN MILLIMETERS)

	Length	Width	Thickness
Plastron as a whole	309.0	223.0	....
Anterior lobe	80.0	145.0	....
Posterior lobe	86.0	157.0	....
Epiplastral lip	48.5	72.0	....
Section 1	....	73.0	19.5
Section 2	....	....	19.2
Section 3	....	....	4.0
Section 4	....	....	39.5
Section 5	....	....	16.0
Section 6	....	...	13.8
Anal notch	21.0	58.0	....
Entoplastron	60.5	57.0	....

The configuration of the entoplastral bone in this species is rather distinctive. Its outer surface is roughly octagonal. in outline with a tapering anterior margin bearing a small angle behind the gulo-humeral sulcus, and another at the epihyoplastral suture. The lateral margins in back of the epihyoplastral suture are roughly parallel to the long axis of the plastron and the posterior margins lie almost at right angles to the axis. The outline of the visceral surface, Pl. IV, fig. 1, is hexagonal. *T. laticunea* Cope [1] and *T. amphithorax* Cope [2] from the White River, Oligocene beds of Northeastern Colorado, possess entoplastra which are somewhat similar to that of *T. ducateli*.

The plastral sulci of this new species are all well defined and are indicated on the figures. There was a slight en-

[1] O. P. Hay, op. cit., 1908, p. 403, fig. 510.
[2] O. P. Hay, idem, 1908, p. 408, fig. 529.

croachment of the plastral scutes on the peripheral bones and a much smaller overlap of the marginal scutes onto the plastral elements. Marginal scute four projected a very slight distance upon the hyoplastral bone near the axillary notches. The pectoral scute of the plastron overlapped on peripheral four; the abdominal scute upon peripherals five, six and seven and the inguinal scute on peripherals seven and eight. The inguinal scute was rather large and roughly rectangular in outline.

This Miocene specimen seems to be different from any known fossil or recent species. It is named for Prof. J. T. Ducatel, Maryland State Geologist, 1833–1842.

More than fifty fossil species of *Testudo* have been described from North America. At present, the oldest known representative of the genus is *T. uintensis* Gilmore [1] from the upper Eocene, Uinta formation of Utah. Some thirty species are recorded from the Oligocene and Miocene of the plains and mountain region of the west, from southern Canada to New Mexico and from Wyoming to Kansas. One species occurs in the upper Miocene, Barstow formation of the Mohave desert region of southern California.[2] Pliocene and Pleistocene deposits in Texas, Florida, South Carolina (Tertiary or Pleistocene?) and Tennessee [3] have furnished about twenty species, but only three or four are known from contemporaneous beds of the west, in Kansas and Nebraska. American species of *Testudo* exhibit considerable diversity in size. The smallest member of the genus is probably the Tennessee Pleistocene *T. munda* Hay that was less than five and one-half inches in length. The largest North American species and probably the largest land tortoise known at the present time, is *T. louisekressmanni* Wark [4] from the Pliocene of Florida. The

[1] C. W. Gilmore. "Fossil Turtles of the Uinta Formation," *Mem. Carnegie Mus.*, vii, p. 150, Nov. 1915.

[2] J. C. Merriam. "Tertiary Mammalian Faunas of the Mohave Desert," *Bull. Dept. Geol. Univ. California*, xi, pp. 450, 456, 527, 533, 1919.

[3] O. P. Hay. "Descriptions of some Pleistocene Vertebrates Found in the United States," *Proc. U. S. Nat. Mus.*, No. 58, p. 86, 1920.

[4] H. F. Wark. "A New Giant Tortoise from the Pliocene of Florida," *Amer. Jour. Sci.*, 5th ser., 17, pp. 400, May 1929.

carapace of this species had a very high arch and is estimated to have been over seven feet long. Therefore it was larger than *T. atlas* (Falconer and Cautley), another giant species, from the Pliocene of the Siwalik Hills, India, which is reported to have reached a length of six feet.[1]

The fossil record thus far, seems to indicate that *Testudo* had a greater development in the Eocene than actual discoveries would lead one to suspect and that by middle or upper Miocene time the group ranged from coast to coast in the United States. In the Pliocene and particularly during the Pleistocene, its distribution was restricted very largely to the southern part of the country, save for the three or four forms that are known from Nebraska and Kansas. Climatic changes accompanying Pleistocene glaciation may have been dominant factors in the retreat of the group southward from the western area in which it was so well represented during Oligocene and Miocene times and the final extinction of the group in the southern region may have been due to the combined action of carnivorous enemies and further climatic changes that the creatures could not withstand.

Three recent species of land tortoises inhabit the southern part of the United States, from South Carolina and Florida to the deserts of Arizona and Southern California. They have often been included in the genera *Testudo* or *Xerobates* in the past, but more modern usage assigns them to the genus *Gopherus*.

Chelonians as an Index of Climate

The several genera of chelonians in the marine Calvert formation are of interest for the import that they may have relative to the probable climate and nature of the land bordering the Calvert sea. Inferential evidence of climatic conditions from studies on the molluscan fauna and the flora of the Calvert formation indicates more mild conditions than those prevalent at the present time. The invertebrates according to Dall,[2] suggest that temperature conditions prevailing during

[1] O. P. Hay, op. cit., 1908, p. 367.
[2] W. H. Dall. Maryland Geol. Surv., Miocene report, p. cxlix, 1904.

deposition of the Miocene sediments in Maryland were temperate and somewhat warmer than at present. A land plant assemblage from the Fairhaven diatomaceous earth member, at the base of the Calvert formation, from a locality near Washington, D. C., was studied and described by Berry,[1] who stated that the florule suggests a region of dunes similar to the Santa Rosa peninsula between Pensacola Bay and the Gulf of Mexico and that it seems to be comparable with existing coastal floras of South Carolina and Georgia or of the Gulf coast from western Florida to eastern Texas. The diatom flora according to Dr. Albert Mann [2] also indicates a relatively warm or subtropical temperature.

The geographical ranges of the several groups of turtles seem to be very closely circumscribed by climatic conditions. The habits of fossil representatives of these groups may have been similar to those of the recent forms and their distribution therefore equally dependent on temperature and moisture. *Psephophorus* is an extinct genus belonging to the leather back or trunk turtles. They are represented in the existing seas by a single genus and species, *Sphargis* or *Dermochelys coriacea* (Linnaeus), which has, according to Gadow,[3] a wide distribution ranging over all intertropical seas and only accidentally visits the northern coasts. The pleurodires have been discussed at length in the remarks under *Taphrosphys miocenica* therefore it will suffice here to add the fact that many if not most of them inhabit regions where the mean annual temperature is much higher than that now prevalent in Maryland. Recent members of the *Cheloniidae* are found in the Atlantic, Indian and Pacific Oceans and normally occupy the warmer parts of these seas. Many of the recent species of *Testudo* and those belonging to the closely related *Gopherus* inhabit rather arid regions and some, the deserts proper. They often dig deep burrows and hide in them during the hottest part of the day or during stormy weather.

[1] E. W. Berry. The Physical Conditions Indicated by the Flora of the Calvert Formation, U. S. Geol. Surv., Prof. Paper 98, pp. 61–73, May 27, 1916.

[2] E. W. Berry, idem, 1916, p. 62.

[3] H. Gadow, op. cit., 1901, pp. 333–4.

A discussion of the gopher turtles by Ditmars [1] states that all three North American species have similar habits; they seem to prefer dry sandy areas, require considerable warmth (from 75 to 95 degrees Fahr.) and can not survive dampness. *Gopherus polyphemus* (Daudin) is common in the sand hill region of Hampton County, South Carolina.

The assumptions that may be drawn from the occurrence of *Testudo* and the other chelonian remains in the marine Miocene beds of Maryland are in accord with deductions derived from the invertebrate fossils and particularly with those from the plant remains. All point to a warmer climate than that prevailing at the present time. A definite determination of the mean annual temperature in the Maryland region during the deposition of the Calvert beds can never be attained, but a more or less close approximation may be inferred from the fossil evidence. The mean annual temperature at Solomons Island at the south end of Calvert County [2] is 56.7° Fahr. On the other hand, the mean at Beaufort,[3] which lies to the east of Hampton County in southern South Carolina, is 67° Fahr. Temperature conditions prevailing in Maryland during the Miocene may have been comparable to those at Beaufort today, but were probably somewhat higher.

[1] R. L. Ditmars. *The Reptile Book*, pp. 65–71, 1922. Doubleday, Page & Company.

[2] Maryland Geol. Surv., Calvert County report, p. 183, 1907.

[3] Handbook of South Carolina, State Department of Agriculture, Commerce and Immigration, p. 68, 1908.

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ABBREVIATIONS USED ON PLATES

a, accessory bone; *AB*, abdominal scute; *AN*, anal scute; *cb*, costal bone; *CS*, costal scute; *ent*, entoplastron; *epi*, epiplastron; *FEM*, femoral scute; *GU*, gular scute; *HUM*, humeral scute; *hyo*, hyoplastron; *hypo*, hypoplastron; *IG*, intergular scute; *IN*, inguinal scute; *M*, marginal scute; *n*, neural bone; *p*, peripheral bones; *PEC*, pectoral scute; *V*, vertebral scute; *xiph*, xiphiplastron.

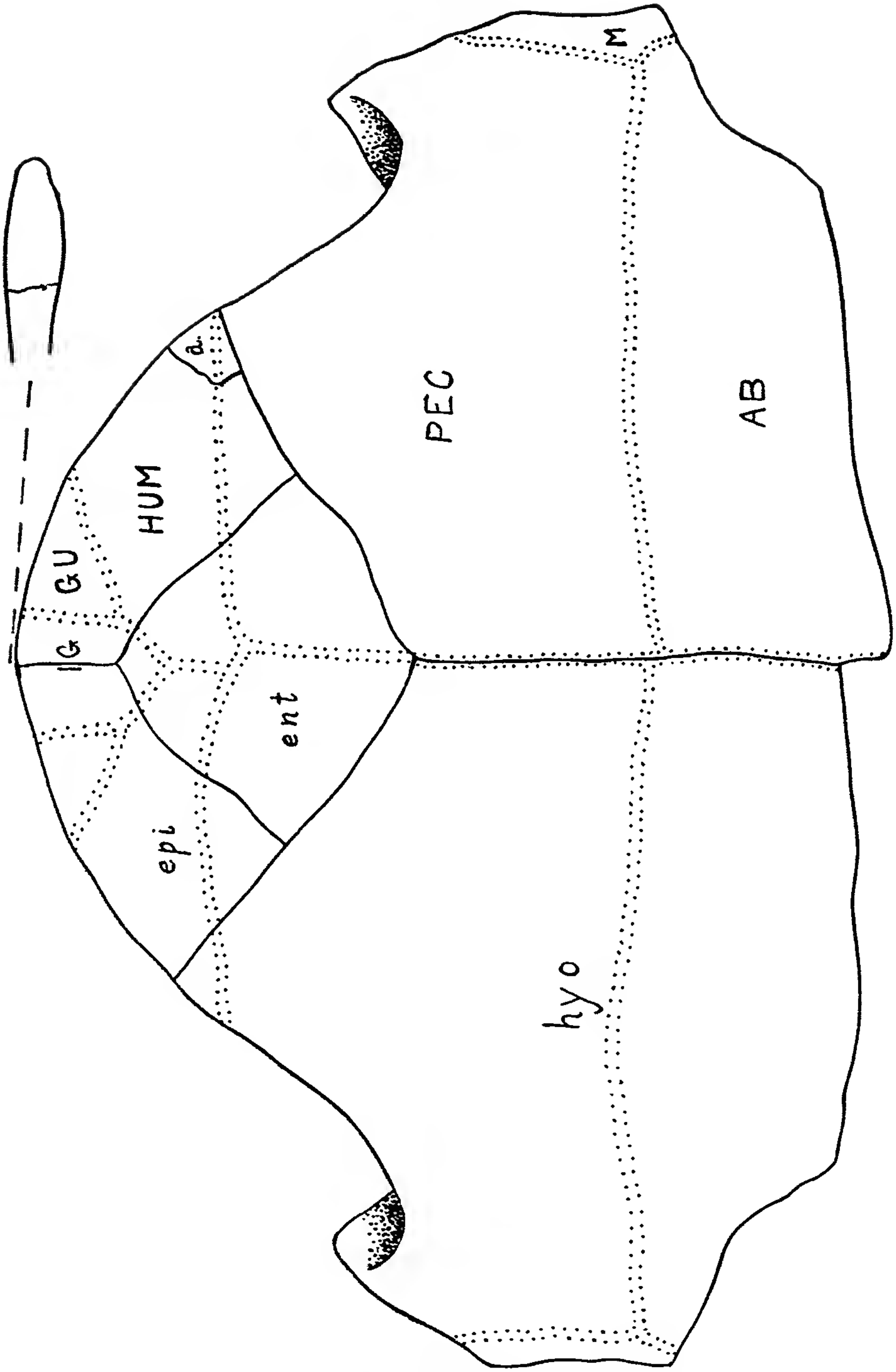


PLATE I. *Taphrosphys miocenica* Collins and Lynn, n. sp. Type. × 0.5. Anterior lobe of plastron.

PLATE II

Plate II. *Chelonia marylandica* Collins and Lynn, n. sp. Type. × 0.6. Median portion of carapace

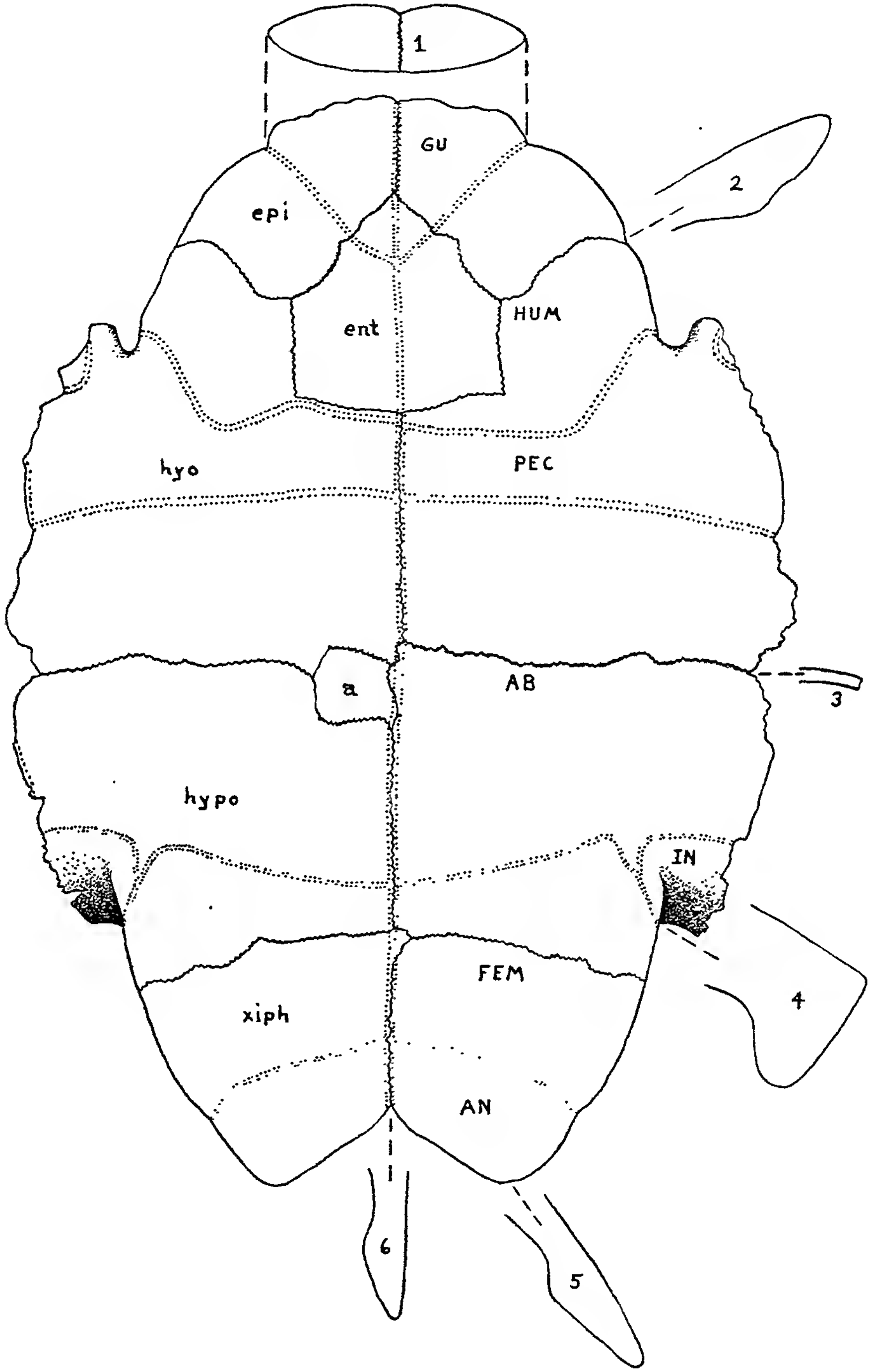


PLATE III. *Testudo ducateli* Collins and Lynn, n. sp. Type, × 0.5. Plastron.
FIGS. 1–6. Sections at points indicated by the broken lines.

PLATE IV

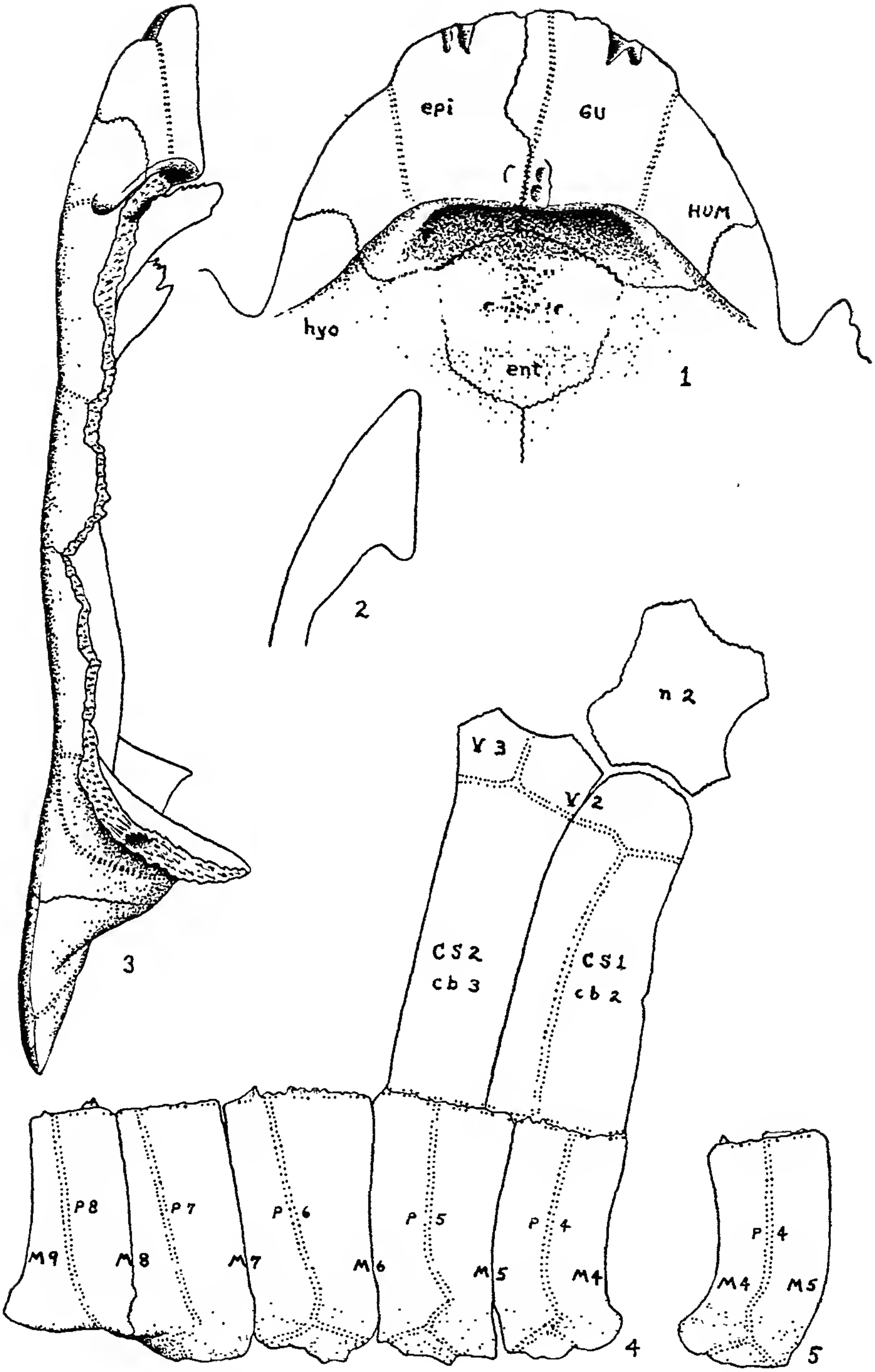


PLATE IV. *Testudo ducateli* Collins and Lynn, n. sp. Type, × 0.5. FIG. 1. Upper surface of anterior end of plastron. FIG. 2. Section at epiplastral suture. FIG. 3. Left lateral view of plastron. FIG. 4. Portions of right side of carapace and the second neural. FIG. 5. Fourth left peripheral bone.

A NEW TURTLE, PERITRESIUS VIRGINIANUS, FROM THE MIOCENE OF VIRGINIA

CHARLES T. BERRY AND W. GARDNER LYNN

WHILE visiting Stratford Hall, Virginia, the birthplace of Robert E. Lee, on June 24, 1935, the authors received permission from Major-General B. F. Cheatham to collect from the bluffs which front upon the Potomac River in that region. The present paper is the outgrowth of this visit and a later one on August 9, 1935. These bluffs appear on the Areal Geology Map in the Nomini Folio [1] of the U. S. Geol. Surv. as being located in Westmoreland County, Virginia, forming about seven miles of the southern shore of the Potomac River and are designated as the Nomini Cliffs. However on a more recent map [2] showing the boundary line between Virginia and Maryland the term Nomini Cliffs appears as restricted to those bluffs at the eastern end, just west of Currioman Bay. The remaining bluffs to the west are given two names, Horsehead Cliffs and Stratford Cliffs. The former is the westernmost one and is situated near Pope Creek. Likewise on the 1932 Wakefield Quadrangle the three cliffs are distinguishable as Horsehead, Stratford, and Nomini Cliffs. In Mansfield's paper of 1926 [3] concerning the age of the Nomini Cliffs the author does not make clear whether the cliffs he calls "Nomini" are those which embrace all three bluffs or only the one at the eastern end.

The chelonian remains which apparently represent a new species of turtle and are described herein were collected from the Horsehead Cliffs.

[1] Darton, N. H., U. S. Geol. Surv., Geol. Atlas, Nomini folio (No. 23), pl. 1, 1896

[2] Mathews, E. B. & Nelson, W. A., Report on the Location of the Boundary Line along the Potomac River between Virginia and Maryland. Sheets II and III, Baltimore, 1928.

[3] Mansfield, W. C., "Notes on the Occurrence of the Choptank Formation in the Nomini Cliffs, Va.," *Jour. Wash. Acad. Sci.*, 16, no. 7, p. 175, 1926.

Peritresius virginianus n. sp., C. Berry & Lynn.

Type.—Catalogue number 13859, Division of Vertebrate Paleontology, U. S. Nat. Mus. The type specimen consists of the first, fifth and sixth neurals, the first and second suprapygal, and all except the sixth and seventh right and the seventh left costals of the carapace. The plastron is represented by a portion of the left hyoplastron, right and left hypoplastra and the right xiphiplastron. In addition to this, three peripherals, several vertebrae and portions of the right posterior limb and girdle are present.

Type Locality.—These remains were found in the Miocene deposits at the southeastern end of Horsehead Cliffs, Westmoreland County, Virginia.

Horizon.—There seems to be some dispute as to the exact age of the beds which are found in these bluffs north of Stratford Post Office. The earlier writers had the idea that the St. Mary's, Choptank and Calvert formations were all present. However in 1912 Clark and Miller[1] took another view; namely that only the Calvert was represented, but added that there may be some unexposed Choptank in Virginia. In 1926 Mansfield[2] published the statement that only the St. Mary's and Choptank are to be found here, but this is based upon not more than eight invertebrate fossils.

The specimen was found about four feet above the beach level. At a height of about seven feet there appears to be a thin bone bed in which fragments of turtles, cetaceans, fishes and the like occur. The matrix in which the turtle was buried is a blue-gray diatomaceous clay.

Carapace.—The outline of this carapace is cordate. The surface is sculptured with very characteristic grooves and ridges which follow a regular arrangement as seen in Pl. III, fig. 2. In the centers of the costals and near the distal ends the sculpturing parallels the long axis of the bones. Near the lateral edges of the costals it runs at right angles to the intercostal sutures. The ornamentation on the neurals and

[1] Clark, W. B. & Miller, B. L., *Va. Geol. Surv. Bull.*, iv, pp. 129–130, 1912.
[2] Mansfield, W. C., *op. cit.*, p. 176.

suprapygals has no regular pattern. On the first and eighth costals the sculpturing is less characteristic than on the others, its general direction being towards the distal margins of the plates. Around the periphery of the carapace there is a band 5–10 mm. wide where the sculpturing has nearly completely died out.

The carapace has a low arch, being however slightly depressed in the region of the first and second neural plates. Crossing the costals about one-third the distance from the neurocostal suture and running parallel to it there is a very low ridge. This ridge can be traced across both the right and left costals starting on the first, crossing the second, being very prominent upon the third and then dying out so that it is obscure on the sixth and eighth. The neurals, which are arched to comply with the curvature of the carapace, show no evidence of the presence of a median keel. The sulci can be easily traced on all the plates as shown in Pl. I, fig. 1.

The visceral surface of the carapace is complete except for the absence of the proximal ends of most of the ribs. The most important feature to be observed on this surface is the lateral curvature of the ribs. There is a pronounced difference in direction of curvature between the rib on the fourth costal and that on the fifth, the former tending to bend anteriorly while the latter curves posteriorly. A similar difference is apparent in the recent Loggerhead, but appears between the sixth and seventh costals.

The greatest width of the carapace, in a straight line, is 223 mm.; the maximum length, with the width of the seventh left costal estimated, amounts to 389 mm.

On the anterior margin of the first left costal the costoperipheral suture is present for about 30 mm. The same is true on the first right costal for about 8 mm. The variation in the extent of suture present is due to the fact that parts of the anterior portions of the costals are lacking in both cases. The posterior portions of the distal margins of both the first costals possess no sutures at all, the two surfaces forming a thin straight edge. The remaining costals do not possess costoperipheral sutures. Thus only the anterior portion of

the distal margin of the first costal was in contact with the peripherals, while the remaining costals were joined to the peripherals by gomphoses of the rib-ends. The rib-end of the third left costal is nearly complete, extending 26 mm. from under the costal plate. This rib tapers from 14 mm. to 11 mm. in this distance and its dorsal surface is covered by fine grooves parallel to the axis. The rib-ends of the other costals are incomplete or entirely lacking.

It is not necessary to give a detailed description of the individual bones of the carapace; the measurements for all will be found in table I. Observation of the epidermal sulci

TABLE I
BONES

Neurals	Length (middle)		Width (greatest)	
	Type	2nd Specimen	Type	2nd Specimen
1	?	X	22 mm.	X
2	X	57 mm.	X	30 mm.
3	X	57 "	X	30 "
4	X	53 "	X	30 "
5	39 mm.	51 "	24 mm.	30 "
6	33 "	44 "	22 "	29 "
7	X	30 "	X	25 "
Suprapygals				
1	28 mm.	X	54 mm.	X
2	38 "	X	43 "	X
Costals			Width (middle)	
1 R	?	X	47 mm.	X
2 R	?	150 mm.	?	64 mm.
3 R	109 mm.	150 "	?	58 "
4 R	?	156 "	44 mm.	58 "
5 R	?	139 "	39 "	50 "
6 R	X	129 "	X	45 "
7 R	X	103 "	X	40 "
8 R	45 mm.	79 "	26 mm.	36 "
1 L	90 "	X	57 "	X
2 L	96 "	X	49 "	X
3 L	105 "	153 mm.	49 "	60 mm.
4 L	102 "	153 "	?	55 "
5 L	?	149 "	?	48 "
6 L	77 mm.	131 "	36 mm.	45 "
7 L	X	?	X	?
8 L	45 mm.	X	25 mm.	X

Measurements of individual bones of carapace.
X indicates absence of plate. ? indicates complete measurement unobtainable.

reveals that this turtle had five vertebral shields and four pairs of costal shields. In this feature it resembled the existent genus *Chelonia* rather than *Caretta*, for the latter possesses five pairs of costals. Measurements for the horny scutes are given in table II.

TABLE II
SCUTES

Vertebrals	Length		Width (greatest)	
	Type	2nd Specimen	Type	2nd Specimen
2	?	?	53 mm.	?
3	84 mm.	108 mm.	47 "	63 mm.
4	?	?	?	55 "
Costals				
1 R	?	?	?	?
2 R	99 mm.	142 mm.	?	119 mm.
3 R	?	134 "	?	105 "
4 R	X	90 "	X	?
1 L	77 mm.	X	?	X
2 L	95 "	144 mm.	93 mm.	?
3 L	?	137 "	83 "	101 mm.
4 L	?	?	?	?

Measurements of individual scutes of carapace.
X indicates absence of scute. ? indicates complete measurement unobtainable.

The first suprapygal is represented by only two pieces, one a fragment just posterior to the last neural and joining together the two eighth costals, and the other uniting by suture to the inner posterior margin of the eighth right costal. Fortunately the latter fragment possesses a suture at its posterior end which forms a point of articulation with the second suprapygal. In general the shape of the first suprapygal is triangular, occupying the entire area between the eighth costals. It thus agrees with the form of the corresponding bone in existing *Cheloniïdae.*

The second suprapygal is cordate in outline, the anterior margin being sutured while the two posterior lateral margins are not. These latter margins unite in a blunt point forming an angle of about 90 degrees. The lateral posterior margins are thin, but the plate thickens rapidly just anterior to the

posterior end so that the greatest thickness of the plate here is 5.5 mm. The absence of any posterior suture (suprapygo-pygal suture) excludes the possibility that the peripherals united directly with the carapace except in the anterior region. In *Caretta caretta*, in contrast to this, the second suprapygal unites by suture with the pygal.

Plastron.—Only a small portion of the left hyoplastron (Pl. III, fig. 4) is present and this shows no outstanding features. None of the processes are preserved but a part of the hyohypoplastral suture is present. The thickness of the plate is similar to that of the hypoplastron.

Of the two hypoplastra the right one (Pl. IV, fig. 1) is the most complete. Its outer surface is smooth as compared with that of the carapace, but there are faint markings present which radiate from a point near the center of the plate. The right hyohypoplastral suture is lacking except for about 14 mm. The posterior margin, which is very thin, forms a concave arc. On the inner edge of this plate there are seven stylate processes which are situated along the posterior portion of the margin. On the outer edge there are four similar processes and the broken base for a fifth. These processes are likewise confined to the posterior portion of the margin. There is a decided difference between the two sets of processes. Those on the outer margin are very wide and somewhat blunt while those on the inner are narrow and sharp. This plate is nowhere thicker than 5 mm. and in most places much thinner, and is arched at an angle of about 150 degrees. The right xiphiplastron unites with the hypoplastron at the inner posterior corner.

The left hypoplastron (Pl. III, fig. 1) shows the long straight hyohypoplastral suture and three processes on the outer margin. The other edges are irregularly broken so that their original outline can only be surmised. Sulci are faintly visible crossing part of the plate. Those portions of the sulci that could be distinguished have been darkened to accentuate them.

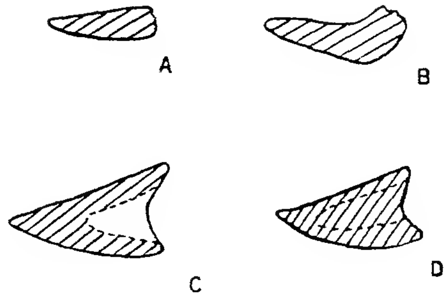
Nearly a complete right xiphiplastron (Pl. IV, fig. 2) is

present. This is a long narrow plate which possesses three rounded striated processes on its posterior end. At the anterior end it articulates with the hypoplastron by means of a series of squamosal sutures. The margins of the plate are thin increasing to a thickness of 6 mm. at the anterior end and 4 mm. at the center. The bone is 90.5 mm. long and 37 mm. wide in the center.

Peripherals.—Of all the pieces of peripheral plates found only three were well enough preserved to warrant short descriptions. These three have been roughly determined as the fourth, seventh and ninth of the left side.

Only the dorsal portion of the fourth left peripheral plate (Pl. III, fig. 5) is preserved. The outer surface is marked by very indistinct grooves and ridges. The costal margin of the plate is a thin straight line. The lower portion curves inward and one is able to obtain some idea of the part that is lacking. The posterior end possesses the remains of a serrated suture, while the anterior end is broken. Across the middle of the plate there can be distinguished an intermarginal sulcus. The interior surface shows the remaining part of a rounded socket into which the rib-end is attached by gomphosis. This plate is 45.5 mm. long and 20 mm. wide at greatest measurement.

There appears to be very little difference between what is identified as the seventh (Pl. III, fig. 6) and ninth (Pl. II, fig. 4) left peripheral plates. The dorsal surfaces of both are slightly concave while their under surfaces are convex, the latter surface of the ninth being a little more arched than that of the seventh. Their cross-sections can be compared in fig. 1. The anterior and posterior ends of both show some remnants of sutures. The outer margins of both are very acute. Intermarginal sulci are present. The outstanding difference between these two plates is the location of the sockets into which the ribs fit. Upon plate seven the socket is found at the posterior interperipheral suture while in plate nine this socket forms a deep oval pit in the center of the plate. Plate seven is 24.5 mm. wide and 55 mm. long while plate nine is 20 mm. wide and 50 mm. long.



Text-fig. 1. Cross sections of peripherals. The dotted lines represent the cavities into which the rib-ends fit. *A*, anterior end of fourth left peripheral; *B*, posterior end of fourth left peripheral; *C*, posterior end of seventh left peripheral; *D*, section of ninth left peripheral.

Other Bones.—Parts of two cervical vertebrae were preserved well enough to be definitely identified. These were the centra of the sixth (Pl. I, fig. 4) and eighth (Pl. I, fig. 3) cervical vertebrae. Some of the corners of the centrum of the former were broken off. The posterior face of this centrum is flat with a shallow vertical groove crossing the surface; its anterior face is deeply concave. The hypapophysis is broken off near its base. Paired articulating surfaces flank the hypapophysis on the anterior ventral side. The centrum of the eighth cervical vertebra is in much better condition than that of the sixth. Its posterior face is convex, while the anterior face is concave. On the dorsal side a wide, deep neural canal is present.

Measurements of the Centra		6th	8th
Length		19.0 mm.	15.0 mm.
Width		15.5 "	17.0 "
Diameter of anterior concavity	Vertical	8.5 "	8.5 "
	Horizontal	10.0 "	14.0 "
Diameter of posterior convexity	Vertical	8.0 "	6.0 "
	Horizontal	13.0 "	13.5 "

Two badly crushed centra (Pl. II, fig. 5) and several broken portions of other centra belonging to the thoracic vertebrae were found. The exact location of these is uncertain. They are hour glass in shape, their articulating surfaces being at the anterior and posterior ends. There is a neural

groove running along their dorsal sides, the margins of which are crushed in on both specimens. These centra are 43 mm. and 33 mm. long respectively.

A practically perfect neural arch belonging to one of the anterior caudal (Pl. II, fig. 2) vertebrae is present. This neural arch is about 10 mm. long. The prezygapophyses are very pronounced while the postzygapophyses are underdeveloped.

The proximal portion of the fifth metatarsal of the right side and two phalanges probably belonging to the same limb were found. The metatarsal fragment is 14 mm. long, its greatest diameter being 5 mm. while the smallest diameter is 2.5 mm. The more perfect of the two phalanges is illustrated (Pl. II, fig. 1). This specimen is 19 mm. long. The greatest proximal diameter is 6 mm., the least proximal diameter 4 mm. The greatest distal diameter is 5.5 mm., the least distal diameter 4.25 mm. Neither of the two phalanges possesses condyles.

The proximal end of the right tibia (Pl. I, fig. 2), was preserved. The head is oval in outline being convex except in one corner where there is a shallow concavity. The shorter diameter of the head is 11 mm. No exact long diameter could be taken due to the broken condition of the bone. There is a deep pit for muscle attachment. The length of this fragment is 32 mm.

The lateral or pectineal process of the right pubis (Pl. III, fig. 3) was found. This bone is comparatively thin, its outer margin being thicker than the rest. The length of the anterior margin is 21 mm. while the length of the inner margin is 19.5 mm.

Additional Representatives of the Species

Fragmentary chelonian remains are of rather frequent occurrence at the horizon where the above-described specimen was found and isolated bones or groups of bones were collected at several other spots along the section. Only one of these collections (U. S. Nat. Mus. No. 13858) was comparable in

completeness to the type specimen and it will be considered briefly at this time. It was found about 0.4 mile south of the one just described and at approximately the same level in the exposure. This individual (Pl. II, fig. 3) was a considerably larger one and is represented by the second to seventh neurals inclusive, the second to eighth costals of the right side and the third to seventh left costals. The matrix in which the remains were imbedded was much weathered, being near the end of a low bluff, and the bones were very fragile so that the visceral surfaces of all crumbled away during their collection and preparation. Fortunately however, the superficial layer of these plates is composed of a rather dense bone and all of the sculpturing as well as the epidermal sulci are thus well preserved. The large size of the individual as compared with the one described earlier, the shallowness of the sulci, and the existence of numerous deeply pitted areas on the shell presumably caused by infective organisms, all lead one to infer that the specimen represents an adult, an animal which had grown larger and been exposed longer to the vicissitudes of life than had the type. Nevertheless, it appears obvious that the two are conspecific, the differences observable all being attributable to a disparity in age.

The maximum length of the portion of carapace which is preserved is 387 mm., the greatest width 330 mm.; in life, the shell was probably at least 500 mm. in length. Although none of the projecting rib-ends are present in the specimen as prepared, several of these were apparent when it was collected and the existence of costoperipheral fontanelles is certain. The measurements of the individual bones are given in table I. It will be noted that although these bones are all larger than the corresponding plates of the type specimen, nevertheless the proportions (ratio of width to length) all agree closely, where comparison is possible. The same statement applies to the epidermal shields, measurements of which will be found in table II. The sulci are extremely shallow and obscure but could be traced with

certainty on all the anterior plates. On the seventh and eighth costals their course is uncertain and is therefore not indicated in the photograph (Pl. II, fig. 3). This indistinctness of the epidermal impressions is in striking contrast to the condition in the type specimen but is believed to be one of the results of advanced age. Similar changes occur in the shells of recent turtles, the outlines of the horny shields being strongly marked on the underlying bones of young individuals but becoming much less prominent with increasing age.[1] Correlated with this, the ornamentation of the present specimen while agreeing in detail with that of the type, is less striking since all the ridges are lower and the grooves shallower. The lateral keels, too, are less sharp and distinct being apparent only on the third and fourth costals as broad humps. A median keel is present on the second neural but can be distinguished on none of the others.

Unfortunately this second specimen supplies knowledge of but a few of the bones which are lacking in the type. The second, third, fourth and seventh neurals are the most important additions, but these exhibit no unexpected features. The presence of the seventh costal on both sides allows us to infer that the eighth neural was hexagonal in outline, although this plate is not preserved. It appears that the two eighth costals approached each other very closely at the mid-line almost, but not quite, meeting.

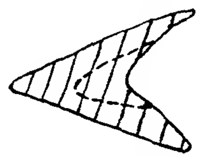
In addition to the specimens from Virginia described above, a number of fragmentary remains representing various parts of the carapace of what may be the same species of turtle have been collected in the Miocene of Maryland from Zones 10, 11, and 12 of the Calvert formation. Since they do agree so well in ornamentation and general proportions with the type of *Peritresius virginianus* they will be given consideration here. The most complete of these specimens (U. S. Nat. Mus. Cat. No. 13785) consists of a costal plate, the sixth of the left side, together with portions of the two adjacent costals (Pl. 4, fig. 3). These were found about one-half mile south

[1] Gadow, H., *Amphibia and Reptiles*, London, p. 325, 1901.

of Parker Creek, Calvert County, in Zone 13 of the Calvert formation. The complete plate is 133 mm. long and has a uniform width of 60 mm. It is 5 mm. thick at the proximal end but decreases in thickness to 3 mm. distally. The adjacent fifth costal is 46 mm. wide. The sculpturing agrees with that of the type specimen, the grooves and ridges running in general parallel to the long axis of the bone. On the proximal two-thirds of the bone, however, they turn at right angles as they approach the intercostal sutures and the ridges tend to be broken into isolated, irregularly arranged tubercles near the proximal border. There is a well-defined lateral keel crossing the costal at 28 mm. from the neurocostal suture. This is more prominent on the fifth costal than on the sixth and thus appears to diminish posteriorly. The sulci indicating the position of the epidermal scutes are shallow, but unmistakable. An intercostal sulcus runs on the sixth costal bone 28 mm. from its anterior border and is 114 mm. long. It crosses the lateral carina. The vertebral scutes thus lay proximad of the lateral keels, the vertebro-costal sulcus on the sixth costal bone being only 16 mm. from the neurocostal sutur. Three other specimens were collected in the same general region. One is the proximal end of what is probably the second costal. Its sculpturing does not differ in any essential from that of the other costals but the lateral keel is much more sharply developed. The second fragment is a nuchal. It measures 51 mm. along the midline and is 60 mm. in width, but the fact that its edges are much worn throws some doubt upon the significance of these figures. The surface sculpturing consists of elongate tubercles like those found on the proximal portion of the costals. The bone has a low median keel which is interrupted by the interneural sulcus crossing the plate at 25 mm. from its anterior border. The third plate is a peripheral measuring 50 mm. long by 27 mm. wide. The free edge is acute as may be seen in fig. 2. Internally there is a deep conical pit for reception of the rib-end.

In addition to these specimens several others serve to

extend the range of the species to the lower zones. From Zone 11 near Dares Beach, Maryland, a single costal, the eighth of the right side, was collected. It is 93 mm. long and has a width of 37 mm. at the proximal end, increasing to about 50 mm. at the distal border. No trace of a keel can be found on this plate. An intercostal sulcus traverses the bone at 16 mm. from its anterior border, but the proximal third of the plate is so worn that the sulci of that region cannot be traced. In a road cut 2.7 miles south of Chesapeake Beach, Maryland, a small exposure of Zone 10 has yielded a single neural, which may belong to this species. It is 50 mm. long



TEXT-FIG. 2. Section through peripheral from Zone 12 of the Calvert formation, Parker's Cr., Md.

and 32 mm. at the widest point, and has a sharp, well-defined median keel. Another neural from Zone 10 south of Plum Point, Maryland, measures 47 mm. by 24 mm. and shows an even higher keel.

Discussion

The fact that this turtle was a member of the Cheloniidae is clearly revealed by many features of its osteology. The low-arched, heart-shaped carapace, the loosely connected plastral elements enclosing large median fontanelles, and the phalanges lacking condyles are all distinctive diagnostic features of the group. The association of the specimen with the genus *Peritresius* appears to be justified by the following considerations. Among the fossil members of the Cheloniidae known from America, only two forms possess ornamentation on the outer surfaces of the bones. These are the genera *Syllomus* and *Peritresius* both of which are, up to the present time, monospecific. The former was

erected by Cope in 1896 for the species *Syllomus crispatus* and was based upon fragmentary materials consisting of a single humerus and portions of two costals collected from Miocene deposits on the Pamunkey River, Virginia. *Peritresius* was also erected by Cope to receive the species *Peritresius ornatus*, a form first described by Leidy but referred by him to the recent genus *Chelone* or *Chelonia*. The types of this species are portions of two peripherals from the Cretaceous of New Jersey. However a nearly complete carapace from the Ripley formation, Upper Cretaceous of Georgia, which was considered by Cope to belong to *P. ornatus* has been described by Hay.[1]

The fact which serves to differentiate these two genera is that in *Syllomus* all the costals articulated with the peripherals by firm sutures while in *Peritresius* costoperipheral fontanelles were present. In the character of the ornamentation the two resemble each other closely although *Peritresius* was a larger turtle. Through the courtesy of the American Museum of Natural History we have been afforded an opportunity to examine the types of *Syllomus crispatus* and the presence of a suture at the distal border of one of the costal fragments has been definitely verified. Hay follows Cope in accepting this character as of sufficient diagnostic significance to justify separation of the genera and it is clear that on this basis our specimens must fall into the genus *Peritresius*.

Hay's[2] diagnosis of this genus is as follows: "Carapace cordate, as in the Cheloniidae generally the anterior peripherals suturally joined to the costals of the first pair; the posterior peripherals joined to costals by gomphosis of ribs only; a high dorsal keel; surface of carapace coarsely sculptured." It will be seen that our specimens agree with this description in all features except the height of the dorsal keel, a character which is certainly of little taxonomic value.

Peritresius virginianus differs from the type species, *P.*

[1] Hay, O. P., "The Fossil Turtles of North America," *Carnegie Inst. Washington*, pp. 210–1, 1908.

[2] Hay, O. P., *op. cit.*, p. 209.

ornatus, mainly in size and in prominence of the carinae. The difference in geologic age is of course, also to be noted.

At the present time the family Cheloniidae as defined by Pratt [1] is represented by seven species which fall into 3 genera. The most numerous and best known of these are: *Chelonia mydas* Latreille, the Green Turtle; *Eretmochelys imbricata* (Linnaeus), the Hawk-bill, which supplies the "tortoise-shell" of commerce; and *Caretta caretta* (Linnaeus), the Logger-head. All enjoy a wide geographical distribution in tropical and sub-tropical seas and are not infrequently encountered as occasional visitors off the coasts of more northerly regions. They are exclusively marine in habit, leaving the water only to deposit their eggs.

The geologic history of the group is of interest chiefly because of the unaccountable gaps which occur therein. *Allopleuron hofmanni* of the Upper Cretaceous of Holland has been generally regarded as the earliest known fossil member of the family from the European continent. It is, however, a highly specialized form with a very greatly reduced carapace and Hay considers it probable that the species really belongs to a family distinct from the Cheloniidae.

A petrifaction from the Cretaceous of Bohemia which was described by Fritsch [2] as a cast of the cerebrum of a plesiosaur has recently been shown by Edinger [3] to be a cast of the skull of a member of the Cheloniidae possibly referable to the species *Chelonia regularis* Fritsch which was based upon a large tibia from the same locality.

In America, the genus *Peritresius* remains as the oldest fossil form. However, we have seen that this turtle is already well adapted for a marine habitat and we must conclude that its ancestors had taken up life in the sea at a considerably earlier period. The number of true Cheloniidae described from the Tertiary is surprisingly small. Two genera, *Lem-*

[1] Pratt, H. S., *Manual of the Vertebrate Animals of the United States*. Philadelphia, pp. 250–1, 1923.

[2] Fritsch, A. & Bayer, Neue Fische und Reptilien aus der böhmischen Kreideformation (II. Reptilien von Prof. Anton Fritsch), Prag, pp. 16–8, 1905.

[3] Edinger, T., Anton Fritsch's "Grosshein von Polyptychodon" ist der Steinkern eines Schildkrotenschadels, Psychiatr. en Neurol. Bladen, pp. 396–404, 1934.

bonax and *Chelonia* from the greensands of New Jersey, represent the group in the Eocene. In the Oligocene, *Bryochelys* and *Chelyopsis* from Belgium and *Carolinochelys* from South Carolina are the only forms known. From the Miocene and Pliocene of Europe a few fragmentary specimens have been doubtfully referred to the genus *Chelonia*. Up to this time, three species have been recorded from the Miocene of the United States, *Syllomus crispatus*, *Procolpochelys grandaeva*, and *Chelonia parvitecta*. These may now be increased by two more, *Chelonia marylandica* Collins & Lynn and *Peritresius virginianus* C. Berry & Lynn. The rarity of members of this family in Tertiary deposits has been mentioned by several authors [1, 2, 3] but it is probable that this is more apparent than real. The loosely knit skeleton of these turtles is not favorable for good preservation for the bones become separated and scattered soon after death. Thus while isolated fragmentary specimens are rather common, associated bones are rare. In any case, it is certain that the turtle remains most commonly met with in the Miocene of Maryland represent members of this group. Fragments of other types of chelonians are infrequent finds in these deposits.

[1] Gadow, H., *op. cit.*, p. 380.
[2] Hay, O. P., *op. cit.*, p. 209.
[3] Zittel, K. A., Handbuch der Paleontologie, Munich and Leipzig, 3, p. 524, 1890.

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EXPLANATION OF PLATES

PLATE I, FIG. 1. Carapace of *Peritresius virginianus* (type) × 1/2. FIG. 2. Right tibia (type) × 1. FIG. 3. Centrum of eighth cervical vertebra (type) × 1. FIG. 4. Centrum of sixth cervical vertebra (type) × 1.

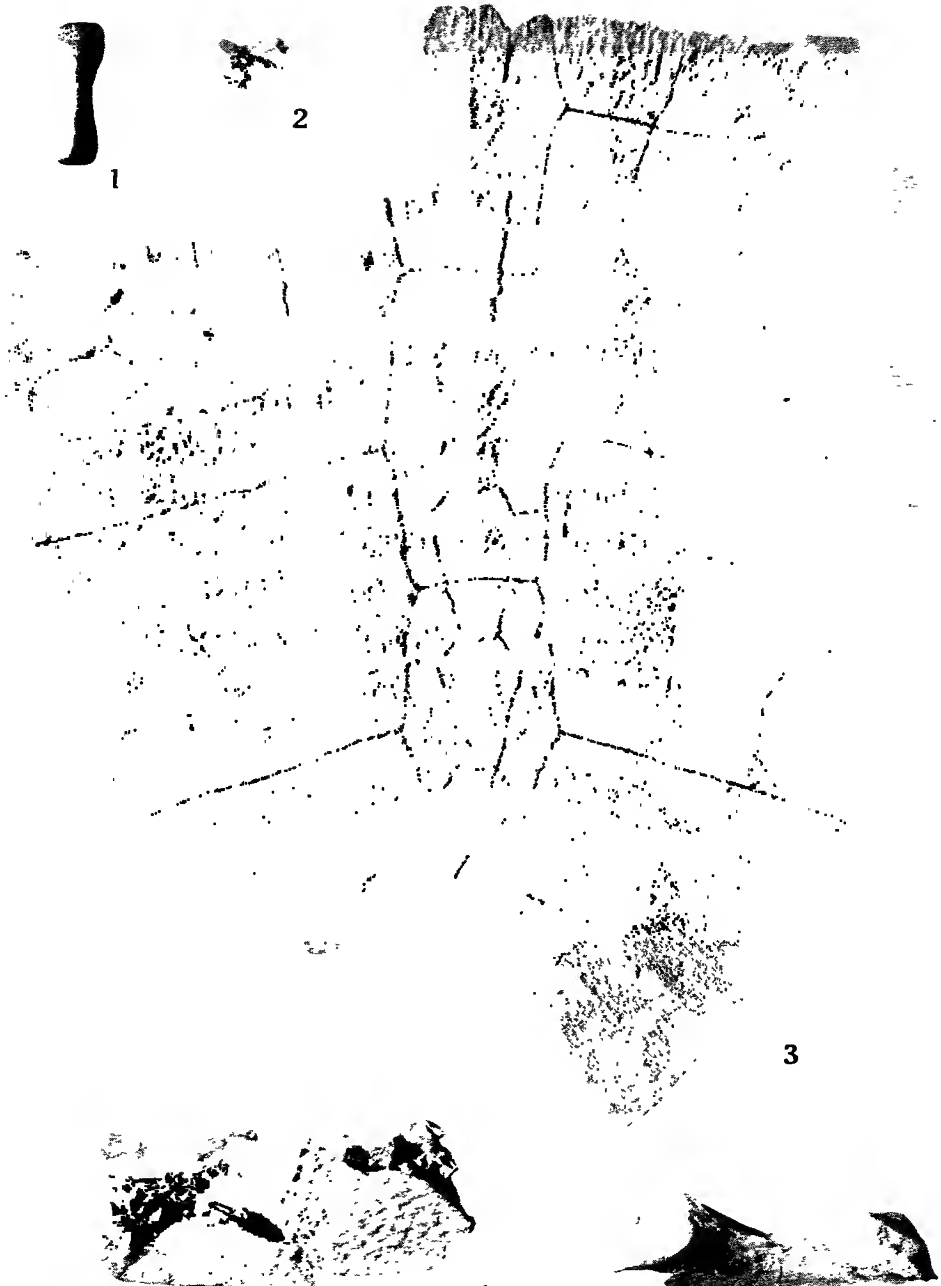
PLATE II, FIG. 1. Phalanx of hind foot (type) × 1. FIG. 2. Neural arch of caudal vertebra (type) × 1. FIG. 3. Carapace of second specimen of *P. virginianus* × 1/3. FIG. 4 Ninth left peripheral (type) × 1. FIG. 5. Centrum of thoracic vertebra (type) × 1.

PLATE III, FIG. 1. Left hypoplastron (type) × 3/4. FIG. 2. Fourth right costal showing sculpturing (type) × 1. FIG. 3. Lateral process of right pubis (type) × 1. FIG. 4. Left hyoplastron (type) × 3/4. FIG. 5. Fourth left peripheral (type) × 1. FIG. 6. Seventh left peripheral (type) × 1.

PLATE IV, FIG. 1. Right hypoplastron (type) × 3/4. FIG. 2. Right xiphiplastron (type) × 3/4. FIG. 3. Portions of fifth, sixth and seventh left costals from Z. 12 Calvert formation, Maryland × 2/3.

1 2 3 4

PLATE II

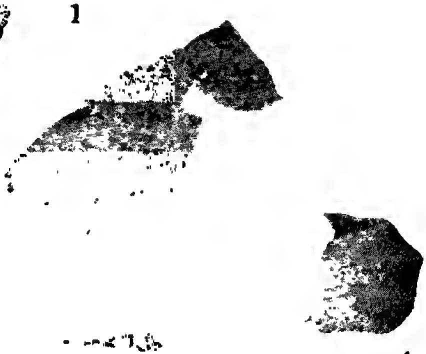


1 2 3 4 5

PLATE III

1

3



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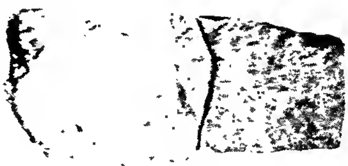

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PLATE IV

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3

AMERICAN LEGAL REALISM *

L. L. FULLER †

THE REALIST movement in American legal thought [1] may be said to have reached its flower within the past five years. There were, to be sure, premonitions of it as early as the beginning of the present century. The realist himself likes to consider his movement as taking its origin in an address delivered by Justice Holmes in 1897.[2] As early as 1912 there existed a systematic formulation of the realist view, however little it may have been noticed.[3] These beginnings should

* The Henry M. Phillips Prize Award was made (October, 1935) to Lon L. Fuller of Duke University for his work on the Science and Philosophy of Jurisprudence, culminated in this article.

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[1] A good bibliography of American legal realism may be found in Llewellyn, "Some Realism about Realism" (1931), 44 *Harv. L. Rev.*, 1222, 1257–1259. It should, perhaps, be pointed out that American legal realism has no traceable connection with the neo-realist movement in American philosophy. On the contrary the adherents of legal realism have for the most part inclined to an epistemology which may be called idealistic in the modern acceptation of that term. This bent is particularly noticeable in Bingham, Cook, Frank and (with less consistency) in Llewellyn.

On the other hand legal realism has a close affinity with the various "descriptive" and "institutional" methods applied by American scholars during the past decade in economics, sociology and political science. In common with all these movements it has in recent years derived much from that philosophy of life known as behavioristic psychology.

[2] "The Path of the Law," published in Holmes, Collected Legal Papers (1921), 167.

[3] Bingham, "What is the Law?" (1912), 11 *Mich. L. Rev.*, 1, 109. While one finds the core of the realist approach in these early articles of Bingham, it is hardly fair to class Bingham with the modern realist school. The principal difference between him and them, as I see it, consists in the fact that he does not, either expressly or impliedly, set up a principle of exclusion. He sought to broaden the field of the legal scholar's research, not to rule anything out of it. The relation between his approach and that of the more recent exponents of legal realism is analogous to that existing between the early experimental psychologists and modern behaviorists. The early experimentalists insisted that muscular reactions ought to be studied; the behaviorist insists that nothing else is worthy of study. Bingham insisted that we ought to observe what courts actually do without assuming that what they do corresponds exactly with what they say; the left-wingers of legal realism seem to assume that this neutral observation of official behavior constitutes the whole of legal science.

suffice to confer at least a semblance of historical respectability on the realist movement. It is not a mere upstart without roots in the past. Yet it is only recently that the realist view has begun to fire the imaginations of legal scholars, that it has provoked men to concerted and sustained "vocal behavior,"—that it has become, in a word, a movement.

Even yet the movement reveals rather conspicuously the defects of youth. It has lived so far largely by the process of discounting its own future. There have been manifestoes, programs for action. There have been discussions of the proper "approach"—conducted for the most part at a respectful distance from the problems to be approached. Recently there have appeared scattered applications of the approach. But we lack as yet a comprehensive work which will both describe and apply the methods of legal realism, which can serve both as an exposition of the approach and as an exemplification of it. We have nothing which could be compared, let us say, to Gény's four volume *Science et Technique*[1] which rounded off a movement for the reform of legal method in Europe.

The nearest approach to such a work is to be found in a book recently published by Professor Llewellyn.[2] It was this book which furnished the stimulus for the present article. Though the remarks which follow are intended as a critical evaluation of legal realism generally, attention will be chiefly centered on Llewellyn and the book just mentioned. There are several justifications for this course. As the realists themselves insist, there is no realist "school."[3] The movement represents a variety of points of view; it has its left and right wings. An attempt to criticize the movement as a

[1] François Gény, *Science et Technique en droit privé positif* (1913–1924).

[2] Llewellyn, *Präjudizienrecht und Rechtsprechung in Amerika, Eine Spruchauswahl mit Besprechung* (1933). A review of this book appears elsewhere in the present issue of this *Review*. See page 551.

[3] Llewellyn, *supra* note 1, at 1254; Yntema, "The Rational Basis of Legal Science" (1931), 31 *Col. L. Rev.*, 925. If in the course of this article I occasionally slip and refer to the "realist school" the offended realist is invited to substitute the word "movement" for "school." He should, however, remember that most schools have been started by men who protested their innocence of any desire to sectarianize their teachings.

whole within the limits of a law review article would break down under the weight of qualification required to take into account the divergencies in the views of particular realists. On the other hand, by centering attention on the work of a single individual we may secure a point of orientation from which the entire movement may be surveyed. There are, it seems to me, good reasons why Llewellyn is entitled to be regarded as the man most representative of the movement as a whole. In the first place, despite the contrary impression sometimes created by his impulsive literary style, he is not a radical. His realism is distinctly of the middle-of-the-road variety. Furthermore, he has written extensively and his writings constitute a more or less comprehensive exposition of the realist view. Finally, more than any other realist he has been willing to expose the premises which are implied in his approach. He is a "philosopher" in the sense that he has the intellectual temerity to reveal the hidden springs of his convictions—at least most of the time.

Professor Underhill Moore with his "institutional approach" has given the realist movement a significant, and in some respects symptomatic turn which deserves a place in any criticism of the movement. Though Llewellyn's writings betray a certain sympathy for the "institutional approach," Moore's contribution remains distinctive enough to require special treatment. Accordingly a section of this article will be devoted to an analysis of his studies.[1]

In what follows I make no claim to dispose of all the questions raised by the realist movement, nor even of all of those raised by the writings of Llewellyn and Moore.[2] I have,

[1] See *infra*, p. 223.

[2] The reader will find valuable and somewhat comprehensive criticisms of the realist movement in Cohen, *Law and the Social Order* (1933), 198–247, 357–362 and *passim:* Dickinson, "Legal Rules: Their Function in the Process of Decision, Their Application and Elaboration" (1931), 79 *U. of Pa. L. Rev.*, 833, 1052; and Pound, "The Call for a Realist Jurisprudence" (1931), 44 *Harv. L. Rev.*, 697.

Llewellyn's answer to the criticism of Dean Pound, which he terms "realistic," seems to me the antithesis of realism. "Some Realism about Realism," *supra* note 1. Llewellyn finds the refutation of Dean Pound's criticisms in the fact that (1) the realists have never expressed in so many words the implications which Pound drew from their writings, (2) when a realist reads his own articles he fails to discover these

however, attempted to select for discussion those problems which seem most intimately involved in the movement as a whole. While, as I have indicated, attention throughout is directed primarily to Llewellyn's work (supplemented to some extent by Moore's studies), I think that most of what I have to say may be applied, with some qualifications and shifts of emphasis, to the position of other legal realists.

Legal Certainty

In one of the most interesting and penetrating portions of his recent book Llewellyn takes up the question of legal certainty.[1] He does not follow the example of those realists who attempt to ridicule this problem out of existence. For him the demand for certainty is something more than evidence of a childish petulance, unworthy of the twentieth century mind. Legal certainty is treated as a genuine social value, and the inquiry whether case law produces it is considered as having an important bearing on the merits of the system as a whole.

Llewellyn takes a needed distinction between: (1) predictability of judicial decision, and (2) the ready availability of the materials upon which prediction is based.[2] The first is a matter of legal certainty, the second a matter of legal "system." A body of law may be systematized to a very high degree—so that a lawyer can turn at once to the relevant section of a code, for example—without this implying certainty in the prediction of judicial action. On the other hand (and this *may* be a characteristic of case law), the materials on which prediction must be based may be scattered and difficult of access, without this implying that prediction, when finally arrived at, may not have a high degree of accuracy.

implications in them. It is interesting to speculate what things could be proved by this method. One could prove that the neo-realist movement in American philosophy is not interested in epistemology, that the New Testament does not in any essential contradict the Old. One could even prove that Dean Pound himself is innocent of the oft-repeated charge of Hegelianism.

[1] *Op. cit. supra* note 5, §§ 55–61.

[2] *Id.* § 60.

It is well to have these two notions explicitly separated. There is often a too ready assumption that "system" necessarily implies predictability, and that predictability is impossible without a highly developed "system." On the other hand, it seems to me that Llewellyn goes too far in assuming that the two are completely independent. Surely "system" has generally been something more than a mere indexing device having no connection with the process of decision. As a matter of fact is it not clear that an indexing system which was entirely dissociated from the judicial process would necessarily fail of its own limited purpose?

A more significant contribution to the problem of certainty is found in Llewellyn's distinction between certainty for the attorney and certainty for the layman. For the attorney certainty means predictability of judicial action. It is often assumed that the layman's interest here is identical with that of the lawyer. Llewellyn points out that this is not true. I translate his argument:

> So much for the lawyer. Incomparably more important seems to me to be the legal certainty which the layman demands. . . . It must not be forgotten that the ordinary layman guides his conduct not by *legal* norms but by *social* norms. Often these social norms are similar to those of the law. Seldom is correspondence complete. Legal rules can hardly serve as a guide to life. On the other hand the continuous reshaping and reformulation of social norms . . . does not cease because lawyers have set up legal rules. . . . Legal certainty in business and for the layman does not lie in the fact that an attorney can predict the outcome of a law suit. . . . This sort of calculability is not so important for the layman; it means for him only legal certainty in a particular piece of litigation. For him legal certainty consists rather in the fact that the transaction which he has entered, *if* it gets into litigation, will be adjudged as a prudent man (that is, a prudent *layman* in the particular circumstances) would have foreseen, if he had had in mind at the very beginning the unforeseen dispute.[1]

Legal certainty for the layman is not predictability of

[1] *Id.* § 58. (If the word "certainty" seems somewhat inappropriate to describe the notion here involved, it should be said that Llewellyn uses the German word *Sicherheit* which has a somewhat broader connotation than the word certainty and might have been translated here as "security.")

judicial decision, it is *congruence between legal rules and the ways of life.*[1]

Furthermore, this kind of certainty cannot be achieved unless legal rules *change*. Congruence with lay ways demands a constant reshaping of legal rules, since social norms are continually changing.[2]

This distinction between lay certainty and lawyer's certainty seems to me to be most useful and I have no desire to comment on it, except to express a doubt whether "lay norms" are quite so definite and clear-cut as Llewellyn seems to assume and to suggest that the task of determining the congruence of law and the ways of life is not so simple as he seems to imply.[3]

[1] The phraseology here is mine, not Llewellyn's. I say "congruence" instead of "correspondence" because I take it Llewellyn does not insist that legal rules be *formulated* in the same way as social norms but only that they have ultimately the same points of reference—that they "come to the same thing in the end."

[2] Llewellyn, *op. cit. supra* note 5, at 83. Llewellyn acknowledges that the two kinds of certainty (certainty for the layman and certainty for the lawyer) tend to coalesce, as it were, in those situations where every step of a business transaction is guided by legal counsel. Here lay certainty is a reflection of lawyer's certainty. Llewellyn adds this further observation: In those situations where lawyer guidance is customary there is no great danger of a lack of correspondence between legal rules and social norms. The legal profession is here forced to gain an insight into changing social relations. This collective insight of the profession will tend, in some measure at least, to keep law in step with life.

In the field of lawyer-guided transactions a kind of double safeguard exists. If there is a lack of correspondence between lay ways and the law this is rendered harmless through the guidance of the lawyer. There is not likely to be such a lack of correspondence because the legal profession here cannot be ignorant of the demands of life. Both of these safeguards are absent in the case of those transactions ordinarily undertaken without legal advice.

Llewellyn might have added that there is perhaps still another reason why a lack of correspondence between law and life is unlikely in the field of lawyer-guided transactions. Is it not possible that the conservative influence of the lawyer may have operated to retard social change in these fields?

This whole discussion recalls an observation of Ihering's, that Roman law was workable in spite of its technicality because of the omnipresence of the lawyer, whose services were open to all—gratis. Where legal counsel was not likely to be available (on the battle field, for example) various legal requirements were relaxed. *Geist des römischen Rechts* (7th ed. 1923), II.2, 417.

[3] Underhill Moore's valiant attempt to determine the degree of this congruence in the field of banking law is evidence of the difficulties of the task. Moore and Sussman, "Legal and Institutional Methods Applied to the Debiting of Direct Discounts" (1931), 40 *Yale L. J.*, 381, 555, 752, 928, 1055, 1219. In spite of the elaborateness of the method the results of this research seem to me to remain inconclusive.

There is, however, another point about legal certainty which Llewellyn does not discuss at any length, but which it seems to me deserves careful consideration. I mean the question, what will be the probable effect on legal certainty, *i.e.*, on "lawyer's legal certainty," of an adoption by courts of the approach recommended by the realist school? The realist school has generally evaded this question, not because it was embarrassed by it, but because it considered it unimportant. One realist tells us that the really enlightened and normal person takes a "positive delight in the hazardous, incalculable character of life," and regards "life's very insecurity" as its "most inviting aspect." [1] The implication seems to be that for the person free from psychic repression legal uncertainty, far from being a source of concern, is really a source of delight.

I have already pointed out that Llewellyn does not embrace this left-wing view. On the other hand, he seems somewhat hesitant to claim that his own approach will create greater certainty than that produced by the method generally followed by courts.[2] In this it seems to me that he and the rest of the realist school have overlooked one of the strongest arguments against the traditional approach.

One of the chief characteristics of the traditional method is that it conceives of the area of the *legally relevant* as quite limited. Only certain types of argument, certain lines of reasoning, are "legal" in nature. Other arguments, other modes of reasoning may have relevance to the decision and may even be taken collaterally into account in deciding the case. But they remain "extra-legal" or "non-technical" considerations, mere (*sic*) arguments of "policy." They definitely occupy a humbler status than "legal" considerations. One of the chief services of the realist school has been to enlarge the field of the legally relevant and to invest "extra-

[1] Frank, *Law and the Modern Mind* (1930), 17.

[2] At the end of section 55 (*op. cit. supra* note 5) he asserts somewhat cautiously that the freer method of decision he advocates will produce a more "effective" legal certainty than the method generally followed. This is preceded by a statement that the freer method will not "endanger" legal certainty.

legal" considerations with a species of respectability.[1] And it seems quite clear to me that this has also been a service to the cause of legal certainty.

The traditional method furnished the judge with a set of legal concepts and said to him, "These are the materials from which you are to build your decision. We realize that in reaching your decision you have been influenced by numerous considerations, many of which have nothing to do with these materials. We are willing to wink at that. But we insist on one condition: When you come to the actual work of construction, you must limit yourself to these materials." But suppose that by no amount of manipulation and ingenuity can the materials furnished be made to build the structure planned. What will happen then? Will the plan be revised? Or will the judge break through the taboo and get what he needs elsewhere? Here lies the source of a great deal of legal uncertainty. And here the uncertainty is directly attributable to the restraints imposed by the "traditional method."[2]

In a pamphlet which served as a sort of manifesto for the free law movement Kantorowicz drew an analogy between the "torture" which modern judges inflict on codes to wring from them the results they consider just and convenient, and the literal torture which judges in the middle ages inflicted on persons accused of crime.[3] There is a surprising parallel between the two phenomena. The middle ages feared and distrusted the judge, particularly the judge sitting in criminal cases. It was thought dangerous to give him much discretion. The law, expressing this common distrust of judges, permitted

[1] It would, of course, be foolish to give the entire credit for this change in attitude to the realist school.

[2] Llewellyn has himself recognized this source of uncertainty in the "traditional method." In 1931 he wrote, "But a fair portion of present unpredictability is certainly attributable to the fact that the courts are using official formulas which fit, only part of the time, what the facts seem to call for. Sometimes the facts win, sometimes the formula." Llewellyn, *supra* note 1, at 1241, n. 45. The idea is also adumbrated in a note in his most recent work. *Op. cit. supra* note 5, at 77, n. 3. It is significant that the discussion of the point is in both instances relegated to a footnote.

[3] Gnaeus Flavius (H. U. Kantorowicz), *Der Kampf um die Rechtswissenschaft* (1906), 49.

the conviction of a criminal only when guilt was proved in certain ways, principally by the confession. This was intended to provide a guaranty that no man should be convicted unless the proof of his guilt was clear and certain. This was the legal theory. The practice is more generally known. What actually happened was that the judge first made up his mind—on the basis of what was then "extra-legal" evidence—whether the accused was guilty. If the decision went against the accused he was put on the rack and compelled to give up, in the form of a confession, the legally acceptable evidence of his guilt.

The traditional conception of legal method imposes a like hypocrisy on the modern judge. Often his procedure is to decide the case first on the basis of "non-technical" considerations. Then armed, not with rack and wheel, but with the intellectual equivalents of those instruments of torture—fictions, analogies, "theories"—he proceeds to wring from his code or other body of doctrine the legally acceptable basis for his decision. The medieval institution of torture was eliminated by the simple expedient of permitting the judge more freedom in passing on the sufficiency of evidence. The intellectual torture which our courts inflict on legal doctrine will be obviated when we have brought ourselves to the point where we are willing to accept as sufficient justification for a decision the "non-technical" considerations which really motivated it.

This millenium, when it arrives, will bring not only a humanitarian reform in our treatment of legal doctrine, but also, I feel sure, greater certainty in the prediction of judicial action. For there are hazards involved in the procedure of putting legal doctrine on the rack which were not involved in the medieval institution. Legal doctrine can sometimes be very stubborn. It may hold its lips tight in spite of all our efforts and ingenuity. Furthermore the modern judge, unlike his medieval predecessor, has the unpleasant duty of spreading on the public record a written description of the process of torture itself. This puts something of a damper

on the intellectual inquisition. And all of these things add to the uncertainties of the process.

In the usual course in personal property the student is introduced to certain cases which are intended to develop a concept of "possession"—usually with especial reference to the law of wild animals. He studies the case of the harpooned whale, the case of the intercepted fox hunt, and many others.[1] After the "doctrines" involved in these cases have been thoroughly digested the instructor puts a series of hypothetical cases—on an ascending scale of temptation, as it were—to test the student's fidelity to the legal doctrine he has absorbed. A great favorite is this case. Two men, *A* and *B*, happen to be hunting in the same swamp. Neither is aware of the other's presence. *A* shoots a duck; it lands in the arms of the surprised *B*. Whose duck is it? I used to put this case to my classes and I generally found a fairly even split of opinion. One group—those who stood steadfast for "legal principle"—were sure it was *B's* duck because he alone had the requisite Power to Control. The other group were sure it was *A's* duck, and, though they were less articulate about their reasons, they intimated a doubt as to *B's* Intent to Possess. After this discussion had gone on for some time, I used to make it a practice to say, "Suppose you knew no law and had never read the cases in the casebook. Whose duck would you say it was?" Immediately there was a subsidence of feelings and argument gave way to complete unanimity. It was *A's* duck. Why? *Because he shot him.*

Now I am not arguing that this is a proper kind of reason, legal or "extra-legal," to assign for a decision, though with some elaboration I think it might be expanded into a respectable argument for the decision in favor of *A*. Nor am I urging inarticulate intuition as a proper basis for judicial decision. What I am trying to say is that from the standpoint of legal certainty no rationalization at all may be better

[1] I think it could be demonstrated that more money is spent by the law schools of the United States in teaching the juristic aspects of fox-hunting than is spent in the actual pursuit of that ancient and worthy sport itself.

than a poor rationalization. Legal scholars are, of course, generally aware that there is danger in hasty systematization. But it is usually assumed that this danger consists merely in the possibility that "system" may work hardship in the individual case. It is ordinarily supposed that even bad "system" will at least carry the compensating advantage of greater certainty.[1] This assumption is demonstrably false. In the illustration I have given "legal theory," far from producing certainty, destroyed a certainty and uniformity which was already present. And in how many fields of the law is this not true?

When lawyers gather informally and argue about the probable outcome of a case pending before a court, about what does their argument usually turn? (I am supposing a case outside the field of public law, a case without any marked "political" complexion.) Do they argue about the judge's conception of proper business policy, about his social philosophy, about how he would decide the case if he were a layman? They may, but they are not likely to. More often their argument will turn on this kind of question: Will the judge take a "technical" view, or will he yield to "non-technical" considerations? This is the source of their uncertainty.[2]

Perhaps I can sum up my discussion with a simile. If you put an animal in too small an enclosure you may rely on it that he will make a violent effort to escape. There is no way of predicting whether he will succeed in this effort, or where he will go if he breaks out. If you put him in a larger enclosure you may be reasonably sure that he will be content to stay inside the enclosure. And if you study your animal's habits closely you will be able to follow his movements

[1] This assumption is made in most of the discussions of the various *Restatements* of the American Law Institute. Professor Havighurst has pointed out that a *Restatement* may bring about uncertainty when it produces a stress in the judicial process such as is described above. Havighurst, "The Restatement of the Law of Contracts" (1933), 27 *Ill. L. Rev.*, 910, 917.

[2] Of course, I realize that this sort of question would still exist, though to a less extent, under a more liberal and realistic conception of legal method. For example, in the interpretation of requirements of formality there is always room for difference of opinion as to how strictly a requirement should be applied.

within the enclosure and discover regularities in them. What we need, as I see it, is a larger grazing area for judges. The realists are bringing this about, and they ought to realize that in doing so they are making the judge a more tractable and predictable animal.

The traditional method places a stigma on "non-technical" considerations. This tends to produce uncertainty for a reason which I have attempted to demonstrate, namely, that we have no way of predicting when the judge will break through the taboo imposed on him. It also tends to produce uncertainty in another way. It prevents these "non-technical" considerations from being talked and written about. It prevents their possible rationalization and systematization.

In our metropolitan centers the work of trial judges is frequently specialized. One judge will hear only criminal cases, another domestic relations cases, *etc.* From time to time it will be necessary to transfer a judge to a class of cases he is not in the habit of trying. This generally produces some consternation among attorneys practicing in the court. They know they are in for a period of legal uncertainty. This may, of course, be due to the judge's ignorance of legal doctrine. More often it is due to his ignorance of the glosses practice has put on legal doctrine. Often there is no way for him to learn of these glosses—these compromises that law has made with life—except to retrace the experience of his predecessors. He finds by the method of trial and error what needs to be read between the lines. Meanwhile litigants are likely to receive arbitrary treatment and legal certainty suffers. Now a legal method, such as the realist school proposes, which would recognize these glosses and compromises as falling within the province of legal science would tend to eliminate this source of uncertainty. If these things were written and talked about the judge might not have to acquire them in the uncertain and painful way he does. Not only that. If these things were openly discussed we should be in a position to attempt a rational and critical evaluation

of them. Out of this evaluation would come greater certainty and greater justice for litigants.

Of course, I realize that there will always remain a fringe of practice which will not get into books. There are many reasons why this is so. But the fact remains that many things are not talked about and do not get into books for the rather prudish reason that they are not supposed to be "law,"—though it is admitted they have a tremendous influence on judicial decision. The absence of these things from books, the fact that they must be "picked up," introduces an element of uncertainty in the law which might, in part at least, be remedied by the general adoption of a more liberal conception of the province of legal science.

Case Law v. Code Law

The American legal realist, though in obvious conflict with his environment, enjoys an advantage usually denied to revolters against things as they are. He is fundamentally satisfied with the "system" under which he lives. The Anglo-American system of case law is entirely to his liking. It fits into his pragmatic conception of legal method. Whatever evils it may seem to display are due not to the system itself but to perversions of it, to the ogre Conceptualism which has taken possession of it.[1] Perhaps this affinity for case law explains why the American legal realist has displayed so little interest in European legal speculation. European realists and near realists—men like Ihering, Gény, Duguit, Ehrlich, Wurzel, Bozi, Sternberg, Kantorowicz, and Radbruch—for the most part go unnoticed in this country.

It would require no elaborate demonstration to show that the realist's assumption of the superiority of the American case system has generally been based on no actual investi-

[1] It has even been suggested that the deficiencies of case law are traceable to "a wave of continental learning [which at one time] swept over England, leaving a thick deposit of its obscurant abstractions, . . ." Oliphant, "A Return to *Stare Decisis*" (1928), 6 *Am. L. School Rev.*, 215, 221. Later in America the process was repeated and "Great cargoes of continental speculations were imported and thrown in to make the dikes of the old abstractions hold." *Ibid.* In this way the pristine pragmatism of our Anglo-Saxon fathers was debauched, and our law became abstract and conceptual.

gation of the workings of case law as compared with code law. The "pragmatism" which intuitively prefers the case method exhausts itself in the preference—it is not applied to determine whether the preference has any empirical justification. This *a priori* pragmatism is not found in Llewellyn's recent book. Partly because the nature of his task demanded it, and partly because his own inquiring temperament led him in that direction, he attempts here something new in the literature of realism: a painstaking examination of the way case law actually operates. He begins by raising an issue of fundamental importance. I translate his own phrasing of the question. "How does it come about that a system of law which develops out of fortuitously selected cases can develop in a way that is tolerable from a political or social point of view? Why does not such a legal system become a planless, orderless chaos of doctrine?" [1]

Under our precedent system courts do not regard themselves as free to anticipate the need for legal rules; they manufacture rules *ad hoc* only, for the particular case in litigation. But what issues will get into litigation? This depends on the interest of individual litigants, and there is, therefore, no way of predicting or controlling the kind of questions which will be the subject of adjudication. In consequence it might appear inevitable that our case law would be spotty and incomplete. A developing field of business practice may be in urgent need of legal direction and control, yet the purely fortuitous circumstance that no individual happens to have an interest in litigation may bring it about that no cases are decided in the field and in consequence no "law" is made.

Now as a matter of fact we know that things do not work out quite as badly as this theory would make it appear. Where legal direction is needed it is generally forthcoming. There are hiatuses in our law, to be sure, but they are neither so numerous nor so extensive as one might be led to suppose in view of the apparently planless way in which our law grows.

[1] *Op. cit. supra* note 5, at 98.

In spite of its dependence on the past, in spite of the lack of conscious direction over its growth, our system of case law has generally proved itself capable of meeting new social conditions. How does this come about?

Llewellyn solves this problem in a way one might have anticipated. Litigation is not purely a matter of chance and individual interest. Litigation arises out of conflict. Conflict in turn arises in those fields of social activity where growth is taking place, where the relative strength of interest-groups is changing. Things are so arranged that where changing social practice demands new law individual interest will see to it that suits will be brought which will furnish a substratum for the elaboration of the needed doctrine. There is happily a kind of automatic correlation between the interest of the individual litigant and the social need for new law.

That there is an element of truth in Llewellyn's solution of this problem is pretty obvious. It is equally obvious that the solution is partial and incomplete. The correlation between the interest of the individual litigant and the interest of society in legal development—like the correlation assumed by classical economics between the individual economic interest and the common good—is unfortunately far from complete. It is scarcely necessary to demonstrate that our courts' piece-meal and backward-looking system of legislating frequently proves inadequate to meet the need for legal control in fields where social practices are changing rapidly. There are many reasons why this should be so. If the growth in social practice is at all rapid it is likely that with our crowded court calendars case law cannot keep up with it. Again, though the change in social life may involve the interests of whole sections of the population, the pecuniary interest of any individual may be so slight as to make litigation (or at least appeal to the upper courts) impracticable.[1]

[1] An example of this is to be found in the field of what is called "industrial insurance."

The history of regular life insurance, on the other hand, justifies pretty well Llewellyn's optimism concerning the ability of case law to deal with new situations.

I do not for a moment believe that Llewellyn meant to assert any complete and nature-given coincidence between the interest of the individual litigant and the social need for new law. Perhaps he would recognize the need for the qualifications suggested here. But if that is so it must be confessed that his own treatment of the subject leaves too much to inference and presents, at most, intimations of the darker side of case law.

After proving that case law will, or is likely to, grow to meet new social conditions, Llewellyn points out that there are things which may operate to prevent that growth from being a healthy one. Often a whole field of law is influenced permanently by the particular turn taken by the first case arising in the field. This case may have carried a certain factual and ethical complexion which was actually the determinative element in its decision. The court in deciding it, however, may lay down a categorical rule which subsequently becomes divorced from the particular circumstances

A whole new field of social practice grew up with life insurance and, as was inevitable all sorts of abuses grew up with it. *A priori* one might argue that this is the kind of situation case law is not adequate to meet. Yet we know that, in general, the courts saw that the problem of life insurance was really a *new* problem, and they remade the law to fit this new field. They refused to apply in this new field the supposedly fundamental principles of contract, tort and agency law—not, to be sure, without causing some distress to the student writers of law review notes.

The history of standard life insurance is repeating itself, so far as social practice is concerned, in what is called "industrial insurance." Industrial insurance is written in small amounts (say $100 to $500). Premiums are collected weekly. The policy is issued without a medical examination, though not without warranties concerning the health of the insured sufficiently inclusive to make most of the policies issued void if these warranties were taken literally. It is no exaggeration to say that the abuses which have arisen out of this type of insurance are appalling. Many of the policies are so worded as to bind the companies to practically nothing. Not infrequently a large portion of the premium is paid for disability insurance which *is cancellable at any time by the company*. Of course, the practice is not as bad as these provisions might imply. But it is bad enough. And all of these social abuses are growing up without judicial curb. Why? For the very obvious reason that the amounts involved are too small to attract lawyers to undertake litigation. The man of moderate means, who takes out regular life insurance, has been freed from abuses of this sort by the courts—even if the courts have had to hurt the juristic sensibilities of legal theorists in order to do it. But the poor man remains a victim of the rapaciousness of the less responsible insurance companies. Is not the general indifference toward his plight in some part the product of our faith in the capacity of case law to take care of new problems? We think in terms of case law, and *we assume that the need for statutory reform is not really pressing until it makes itself manifest in the decisions.*

of its first utterance and controls perhaps hundreds of cases which from an ethical or "factual" viewpoint are quite different from the first and "critical" case. There is an even more sinister possibility. Organized interest-groups, aware of the importance of such critical cases, may see to it that these cases "come up in the right way." Thus by the expenditure of a little money and effort at the right time the whole future development of a field of law may be influenced.[1]

Llewellyn fails to mention another element of contingency in the growth of case law which it seems to me is necessary to complete the picture. I refer to the fact that it is a matter of chance *in what order* cases will arise, and what the *doctrinal* connection will be between the cases which do arise and those already decided. Just as a whole field of law may be influenced by the accidental *presence* of a particular case at a particular stage of its development, so a whole field of law may be influenced by the accidental *absence* of a decision which might serve as a sort of *doctrinal bridge* between existing rules and needed new law.

The case of *Shuey v. United States*[2] decided that the published offer of a reward might be effectively revoked by an announcement given equal publicity. Pollock in his treatise on contracts admits the reasonableness of the decision but adds the remark that it "seems a rather strong piece of judicial legislation."[3] Why this? Because previous decisions had declared that a revocation takes effect only when "communicated." This revocation had not been "communicated" since it had never come to the knowledge of the claimant of the reward. Now suppose that there had intervened between these previous decisions and the case of *Shuey v. United States* a case in which a letter of revocation had been promptly delivered at the place of business of the

[1] Llewellyn, *op. cit. supra* note 5, at 100. This notion of the "critical" case is obviously realism of the right-wing variety. It assumes that the "vocal behavior" of courts has a significant influence over the judicial process. Llewellyn has elsewhere declared that the position on which some realists verge, that "rules" have no influence over judges at all, escapes his understanding. Llewellyn, *supra* note 1, at 1241, n. 46.

[2] 92 U. S. 73 (1875).

[3] *Principles of Contract* (4th ed. 1885), *20.

offeree and had been allowed to remain unopened on his desk. Without much question a court would have held that such a revocation was "communicated" so soon as the offeree had had a fair opportunity to become familiar with it. And had such a case existed before the *Shuey* case is it likely that anyone would have regarded that decision as a "strong piece of judicial legislation"? Pollock's attitude was influenced by the purely fortuitous circumstance that there did not exist a case which could operate to carry his mind, without shock, from the older cases to the decision in the *Shuey* case.

The possibility that a doctrinal bridge may be lacking represents, then, an additional element of fortuity in the development of case law, operating to make the litigant's rights depend on the chronological order in which his case comes up. Furthermore it is an element which is especially likely to be operative in fields where social practice is changing rapidly. Social practice may change so rapidly that by the time cases actually get into litigation they are so far removed from what the court is familiar with that the court is left without any intellectual conduit to carry it from the old to the new.

It may be argued that the need for "doctrinal bridges" is not a peculiar fault of the case system, and that the whole thing can be reduced to a psychological truism, that men's minds hesitate at making violent jumps. This may be so, but I think it can be shown that this native intellectual skittishness of man is aggravated by the methods of reasoning necessitated in a system of case law. Under a code courts are, of course, faced with the same problem that faces our common-law courts, that of deciding cases which do not fall within existing doctrine. But the procedure under code law is generally to bring the unforeseen situation within some very general provision of the code, vague enough not to interfere with the proper decision of the case and just definite enough to appear to give the court some support. Where a large number of such general provisions are available, as they are in most codes, "doctrinal bridges" are not necessary. The

statute itself will carry you anywhere you want to go. The doctrinal bridge becomes important in a system of code law where a somewhat specific provision is gradually extended to cover situations not originally comprehended within it. Here the order in which cases come up is important, and if the cases which lie just beyond the literal meaning of the section arise first, the process of extension will be accelerated. In a system of case law we have, for the most part, nothing corresponding to the catch-all provisions found in codes. Of course, one will find laid down in the cases some rather broad and general principles, but their apparent scope is generally limited by being given a point of reference in the particular case at hand. Such general principles as we have in case law lack the authoritative force which backs a statutory enactment. They are apt to be relegated to Austin's field of "positive morality." They are not quite law. The full force of precedent applies only to the particular decision. All this means that the doctrinal bridge will necessarily play a more important rôle in case law than it does under a code. And, as I attempted to show, it is an alogical, fortuitous factor.

Incidentally this whole discussion gives point to a statement once made by Ihering which would probably be disturbing to the orthodoxy of most realists.[1] The statement was that Roman law was great because it was built upon a system of "case law" which did not discriminate between real and hypothetical cases. The jurisconsults gave answer to all cases put to them, without inquiring whether they were real. This gave a continuity to the body of doctrine which they developed which cannot exist where only "real" cases are dealt with.

Legal Rules and the Nature of Concepts

An attitude of scepticism toward rules has characterized the realist movement from the beginning. This scepticism rests on two closely related grounds. The first lies in a conviction that "reality" is a thing too complex, tumultuous,

[1] *Geist des römischen Rechts* (4th ed. 1858), II.2, 385–386

and vital to be kept in a straight-jacket of rules. I shall deal with this aspect of the realist's scepticism later under the heading *Law and Society*. The other ground for his distrust of rules lies not so much in a belief in the impossibility of the task imposed on rules as in a belief in the essential impotence of rules themselves. Rules are made up of concepts, and concepts are but the shadowy figments of our own minds, wholly unworthy of the simple faith the conceptualist places in them. It is with this aspect of the realist's scepticism that we are here concerned.[1]

The realist movement has done an immense service to American legal science in inculcating in it a healthy fear of such very real demons as Reified Abstractions, Omnibus Concepts, and Metaphors Masquerading as Facts.[2] One seldom encounters a law review article today of the type so common ten years ago, in which the writer starts with an inquiry into the "nature" of some legal concept and ends by deducing all sorts of important consequences from the supposed inner nature of the concept—without more than a passing reference to the practical effects of his conclusions, and then with an air of condescension, as if to compliment the facts for showing good judgment in conforming to his theories. The outstanding foe of this sort of verbal trifling has been Professor Cook. There can be no doubt that his influence, and that of other realists like him, has been in the main beneficent.

On the other hand, it seems to me that we are now in danger of carrying the crusade against "conceptualism" too far. American legal science gives evidence that it is on the verge of making an orthodoxy of the sterile and uninspired behavioristic philosophy which has worked such havoc in the other social sciences. Professor Cohen has been warning

[1] Valuable criticisms of the realist's attitude toward rules will be found in Cohen, *op. cit. supra* note 8, and Dickinson, *supra* note 8. Dickinson is not merely critical, but presents a carefully thought-out theory of his own in which he makes use of so much of the realist theory as he considers acceptable.

[2] I have attempted a contribution toward the cause myself. See Fuller, "Legal Fictions" (1930–1931), 25 *Ill. L. Rev.*, 363, 513, 877.

against this danger for a long time, and one only wishes his warnings had a more discernible effect. There is so much breadth of learning and sound sense in what he has written that I hesitate to attempt any supplementation of it. Nevertheless I think I may contribute something in the matter of diagnosing the disease.[1]

Professor Cohen calls the rule-phobia of the left-wing legal realist "nominalism."[2] Now one gets into all sorts of difficulties if one attempts to explain just what is meant by nominalism in the ontological sense. This is not the place to enter into that problem.[3] Let us, therefore, use the word nominalism frankly as a term of opprobrium, as meaning a *too* distrustful attitude toward universals and abstractions. Now what is the cause of this attitude? This is the question which has not been sufficiently examined. We can never rid a man of a disease of thought until we know how and why he succumbed to it. As I see it, the realist's nominalism generally arises from an error of psychology. This error may be stated as the belief that the individual in his own private thinking does not employ universals and abstractions and that these things are only convenient devices for the communication of ideas. It is the notion that in the internal economy of the mind only "things" are dealt with, and that abstractions and concepts are simply packages of these "things" bundled together,—for export purposes, as it were.

Nominalism is usually defined as the belief that universals exist only in the mind of the individual. So far as the origin of the nominalist attitude is concerned it seems to me that this inverts the thing. Nominalism starts with the assumption that in the mind of the individual universals have no

[1] In the matter of diagnosis I feel I enjoy an advantage over Professor Cohen. I have suffered from the disease myself. In my discussion of the "fictitious" nature of classes (in the article cited *supra* note 31, at 877, 884) there is exemplified the same erroneous assumption concerning the use of concepts in thinking that is found in Berkeley, Llewellyn and Wurzel.

[2] *Op. cit. supra* note 8, at 208–247.

[3] Modern epistemologists, incidentally, have developed a very neat device for dodging the problem. It is no longer asserted that concepts and relations "exist," but it is firmly insisted that they do have "subsistence." But what is "subsistence"? Why, that is the kind of existence that things like concepts and relations have!

place, that they are only a sort of social convention making language possible.

Confirmation for this theory of the psychological genesis of nominalism is found in the fact that Berkeley, certainly the greatest nominalist who ever lived, begins his *Principles of Human Knowledge* with an inquiry into the processes of thought in the mind of the individual.[1] The conclusion reached on the basis of this psychological investigation—that abstractions cannot be "conceived" and are mere conveniences of language—is then made the basis for his whole philosophy.

While our legal realists have vied with Berkeley in the extremes to which they have carried the nominalistic attitude, their distaste for "philosophic" discussions has generally led them to neglect any statement of the basis for this attitude. It is, therefore, fortunate that in his recent book Llewellyn has undertaken to discuss in some detail the problem of the nature of concepts and rules. His discussion seems to me to reveal the fact that his fundamental error, like Berkeley's, is a psychological one. I translate a passage from his book:

> To speak of "*applying* the rule" is to use a misleading expression. Rather you either *fill the rule out*, or *put limits on it*. You can only "apply" the rule *after* you have first either included or excluded the case at hand. . . .
>
> Let us assume a case not involving any doubt, but a case nevertheless which would never have occurred to any one at the time the rule in question was established. In spite of this let us assume it to be a case which everyone, after considering it and the rule, would acknowledge would *have* to be governed by the rule. Now I claim there is here no real "interpretation" of the rule. Even here there is an enlargement, a reformulation, an importation of something new into the rule. For the rule consists of a series, a complex of word-symbols. In itself a symbol is nothing. A symbol is.

[1] *Introduction*, §§ 1–25. Cf. ". . . if the nominalistic logic is good it should lead us, as it led Berkeley, to deny that there can be any universal ideas in the mind." Cohen, *op. cit. supra* note 8, at 210. As I have indicated, this statement seems to me to reverse the process by which the nominalistic attitude develops.

however, a means of pointing to things or thought-constructs.[1] In so far as things were *demonstrably* aimed at in the original use of a symbol, the symbol has from the beginning content. Every symbol, however, has to an uncertain degree something which we may call *latent content*, a capacity for expansion, as it were, which, though partly equivocal and unforeseeable, is also in part unequivocal and foreseeable. Some things that are new, some things that have hitherto not been thought of, are nevertheless perceived, so soon as they are considered, to fall at once into the already established category. . . . In our hypothetical case every lawyer would make the same extension. When he does that and does it at once *he does not note the extension.* It appears to him as if the case had always lain within this category, as if it had always been consciously intended that this case should belong to the category. In spite of this he has, though unconsciously, extended the category . . . the legislator could not have *intended* the inclusion of this case *in concreto*, the case was by hypothesis not yet thought of.[2]

The assumption concerning the psychological nature of concepts which underlies this discussion is, I think, demonstrably false. Suppose a legislator enacts that it shall be a crime for anyone "to carry concealed on his person any dangerous weapon." After the statute is passed someone invents a machine, no larger than a fountain pen, capable of throwing a "death ray." Is such a machine included? Obviously, yes. It falls within the "latent content" of the

[1] Llewellyn uses the word *Gedankengebilde* which, in an effort to be fair, I have translated as "thought-constructs," though it might have been translated as "mental images."

[2] *Op. cit. supra* note 5, at 72–74. Llewellyn's discussion rather closely parallels Wurzel's treatment of "projection." Wurzel, "Das juristische Denken" (2d ed. 1924), translated in *The Science of Legal Method* (1921), 298–428.

A similar notion, that in the *Urerlebnis* of the inner soul the mind is freed from the shackles of categories and logic, is expressed in the following passage: ". . . of the many things which have been said as to the mystery of the judicial process, the most salient is that decision is reached after an emotive experience in which principles and logic play a secondary part. The function of juristic logic and the principles which it employs seems to be like that of language, to describe the event which has already transpired. These considerations must reveal to us the impotence of general principles to control decision. Vague because of their generality, they mean nothing save what they suggest in the organized experience of the one who thinks them, and, because of their vagueness, they only remotely compel the organization of that experience." Yntema, "The Hornbook Method and the Conflict of Laws" (1928), 37 *Yale L. J.*, 468, 480. The reader will observe that the nominalist view ("the impotence of general principles to control decision") is here based on an hypothesis concerning the inner processes of thought.

symbol. But does the inclusion of this new machine under the concept "dangerous weapon" *change* or *enlarge* the concept? Yes, says Llewellyn, because the legislator could not have intended to include it at the time he enacted this statute since it was not then in existence. But what *did* the legislator intend "*in concreto*"? Why are we forced to conclude that his intent cannot extend to something not yet in existence? Would Llewellyn contend that the "actual intent" of our legislator could not extend to revolvers of the ordinary type manufactured after the statute was passed? Is it impossible for a man to "intend" a gift to unborn children? Perhaps Llewellyn has in mind the fact that it would be impossible for the legislator to "visualize" the non-existent object when he enacted his statute. But is a man's intent coextensive with the mental images which accompany it? Would it be impossible for a legislator to prohibit the sale of stock in any company organized to manufacture a perpetual motion machine unless he could visualize the machine? In the case of our "dangerous weapon" statute would the accident that there popped into the mind of the legislator the picture of a Colt revolver mean that his intent excluded Smith & Wesson revolvers? No one would contend that. We should have to say, he intended the class "revolvers." But if he can intend the class "revolvers," why not the class "dangerous weapons"? The fallacy underlying Llewellyn's whole discussion is the assumption that thinking must be directed toward particular "things," when as a matter of fact, it may be, and generally is, directed toward classes or universals.

The old notion that the application of a concept involves merely an extraction of something already implicit within it is misleading, though it presents in a metaphorical way one aspect of the truth.[1] Exactly the same thing can be said of Llewellyn's notion that *any* application to "new" situations,

[1] A very readable and interesting refutation of the notion that concepts in some way or other "develop" new meanings out of themselves will be found in 1, James, *Principles of Psychology* (1890), 464–468. Needless to say James does not find it necessary to embrace the notion that any "new" application of a concept is a change in it.

however obvious, effects a "change" in the concept.[1] Indeed, both notions, in so far as they are false, rest on the same error, namely, a hypostatization of the "concept." The old notion treated the concept as an opaque container with all sorts of unknown contents in its interior waiting to be extracted. In Llewellyn's view the concept is—for the individual who uses it—a sort of show case with its contents hung neatly in a row ready to be inventoried at a glance. The fact is that from the standpoint of individual psychology the concept is not a container or "thing" at all, but an activity of the conceiving mind. The "thingifying" comes about when we convert this mental activity into logical terms. It may be that this process of converting a dynamic activity into a static "thing" necessarily involves some distortion. But there is no need to increase the amount of this distortion by the gratuitous assumption that intent and thinking *must* be directed toward "things," and cannot be directed toward classes.[2]

We shall have gone a long way toward ending the controversy concerning "nominalism" if we can secure recognition for the plain fact that the inner mental experience of the individual, however precious and ineffable it may be, is "conceptual." The issue will at least be clarified if we recognize with James that we have available to us "a perfectly satisfactory decision of the nominalistic and conceptualistic

[1] The grain of truth contained in Llewellyn's statement consists in the fact that the application of a concept usually involves a mental operation on the part of the person making the application which did not occur in the mind of the man who first used the concept. If you say, "Man is a wonderful being," and I say, "That statement includes Beethoven," I am making an application of the concept "man" which probably did not "occur" to you; something has happened in my brain which did not happen in yours. But that does not mean that I am *changing* your concept of "man." See 1, James, *op. cit. supra* note 38, at 472.

[2] The difficulty of expressing adequately the principles which we employ in our inner thinking is produced, not by the fact that our inner processes of thought do not employ concepts, but, as Dickinson points out (*supra* note 8, at 1064), by the fact that we often employ in our private thinking concepts and thought-units which do not correspond exactly to those implicit in ordinary language. The difficulty is increased by the fact that these unnamed concepts are peculiarly evanescent. We cannot always call them back at will for purposes of comparison and clarification.

controversy, so far as it touches psychology," and that "We must decide in favor of the conceptualists." [1]

The legal realist is emphatically of those James called "tough-minded." He loves "things"—things that are concrete, tangible, *anschaulich*. In Llewellyn's own words, the realists "want law to deal, they themselves want to deal, with things, with people, with tangibles, with *definite* tangibles, and *observable* relations between definite tangibles—not with words alone; when law deals with words, they want the words to represent tangibles which can be got at beneath the words, and observable relations between those tangibles." [2] Now this intellectual bias, for it *is* a bias, has its value in a science which has suffered for centuries from an unbridled pseudo-rationalism. But like all biases the realist's peculiar bias may sometimes lead him astray. He should remember that not all significant facts are "concrete." He needs to be reminded that the love of the tangible and concrete, like other human loves, may sometimes, when thwarted, fabricate its own object.

Do the Proposals of the Realist School Relate Solely to Method?

The proponents of the realist approach have left an ambiguity in their position which, I think, ought to be removed. Do they propose a different kind of law, or only a different way of talking about law?

On the rare occasions when the realist discusses this question he seems to say something like this: "I am not a philosopher. I have no interest in developing a scheme of ethical values. My only interest lies in seeing that the judicial process is accurately described, that it is recognized for what it actually is. My interest is, therefore, primarily methodological, though it is obvious that good method has a social value of its own. If the judge recognizes what he is really doing, he is less apt to be led astray by delusions as to what he is doing."

1. James, *op. cit. supra* note 58, at 472.
2. Llewellyn, *supra* note 1, at 1223.

On the other hand the enthusiasm for his position which the realist displays seems hard to understand if this disclaimer of any interest in ethics is accepted at its face value. When a man talks with all the zeal of the most ardent social reformer it is difficult to assume that his interest is limited to methodology. When the realist ridicules the "vocal behavior" of courts as an unimportant by-product of the judicial process it is hard to believe that his energies are concentrated on changing this "vocal behavior" and that he has no desire to change anything else.

This ambiguity in the position of the realist ought to be removed. Removing it would clarify discussion. It might have an even more important effect. It might reveal that the realist school—though free from evil intent, of course—has been guilty of the crime of misbranding its intellectual wares. For I strongly suspect that the realist movement has not been so free of "philosophic" pretensions as its proponents would have us believe. Certainly I am not inclined to take seriously Llewellyn's occasional disclaimers that his own approach involves any distinctive ethical bias.[1]

The Relation of Law and Society

One of the fundamental problems which any social philosophy must face may be stated in a somewhat vague way as the problem of the relation between law and society —or, if one prefers, of the relation of Law to Life.[2] Many of the problems of ethical philosophy, in whatever terms they may have been expressed, will be found to center about this relationship. The most imposing legal philosophies will often disclose themselves as involving fundamentally nothing more

[1] "I make no effort here to indicate either the proper rule, or the proper action on any legal subject." "A Realistic Jurisprudence—The Next Step" (1930), 30 *Col. L. Rev.*, 431, at 463. "When the matter of *program* [*i.e.*, of the realists] *in the normative aspect* is raised, the answer is: *there is none.*" Llewellyn, *supra* note 1, at 1254.

[2] Gény's distinction between the *donné* and the *construit* states in a somewhat different form the fundamental relation involved here and has the advantage that its terms are freer from metaphorical contamination than those employed in the text. 4 Gény, *op. cit. supra* note 4, c. 3. However, for present purposes, I have preferred to use the more common terms.

than a bias concerning this relation—a bias in favor of "law," or in favor of "society."

A study of Llewellyn's writings [1] convinces me that he has reached his own solution of this problem. In discussing his solution one is under the embarrassment that Llewellyn nowhere makes as distinct and explicit an avowal as one might wish of the social philosophy which it implies. The difficulty is increased by his failure to put his own view in its historical perspective by indicating its relation to the thought of other writers.[2] There is, therefore, of necessity some conjecture in the account I am about to give, and I warn the reader that it is possible I have misinterpreted his views.

I shall begin by quoting a series of statements which will furnish the background for what I have to say:

[1] In the discussion which follows I draw freely from all of Llewellyn's writings, particularly from the *Bramble Bush* (1930).

[2] The citation of authorities is so often a form of intellectual exhibitionism that one hesitates to criticize a man who is free from this ostentation. Yet it does seem to me that Llewellyn errs too far in the opposite direction. I am particularly distressed at the absence of reference to that great pioneer among "realists," Rudolph von Ihering. There are a number of places in Llewellyn's writings where Ihering's views almost intrude themselves. Llewellyn seems sometimes to imply that prior to American legal realism it had never occurred to anyone to question the "ideology" of the law, or to inquire whether it coincided with the real motivation of legal rules. Yet most of Ihering's life was devoted to ferreting out the social reality concealed behind the "ideology" of the Roman Law. In addition to refusing to accept the conventional formulations of the law at their face value, Ihering also pointed out that there are frequently regularities of judicial behavior ("latent rules" he called them) which do not appear in the rules talked and written about—something which Llewellyn regards as a particularly esoteric discovery of American realism. I. Ihering, *op. cit. supra* note 13, at § 3; cf. Llewellyn, *supra* note 43, at 439, n. 9. Llewellyn speaks of norms (*Sollsätze*) taking on the appearance of affirmations of fact (*Seinsätze*). *Op. cit., supra* note 5, at 89. There is no reference to Ihering's penetrating discussion of the phenomenon. III.1. Ihering, *op. cit., supra* note 13, at 311–326. Beginning on page 96 of the same book Llewellyn discusses the creation of new legal institutions, and describes the process by which existing institutions are diverted to new purposes. A good part of his article, "What Price Contract?" (1931), 40 *Yale L. J.*, 704, is devoted to the same topic. In neither case is there any reference to Ihering's famous discussion of the problem. II.2, Ihering, *op. cit., supra* note 13, at 334–352, 504–537; III.1, *ibid.*, at 281–301. The reader will find portions of Ihering's treatment translated in my article "Legal Fictions," *supra* note 31, at 533–535.

While I am on this subject I should like to take notice of Llewellyn's interpretation of Ihering's theory of interests as an attempt to remove legal science still further from reality than it already was under the notion of substantive rights. Llewellyn, *supra* note 43, at 441. This interpretation is, in my opinion, nothing short of perverse.

"Law and the law official are not therefore in any real sense what *makes* order in society. For them society is given and order is given because society is given.[1] . . . The law then, the interference of officials in disputes, appears as the means of dealing with disputes which do not otherwise get settled. Not as *making* order, but as *maintaining* order when it has gotten out of order.[2] . . . By and large the *basic order* of our society, and for that matter in any society, *is not produced by law*.[3] . . . Law plays only upon the fringes." [4]

Certainly the emphasis is here placed on the "society" side of the relation. Law, the principle of conscious guidance, is relegated to the background, and becomes a kind of midwife called in occasionally to assist the processes of nature, but having no hand in the act of creation itself.[5]

I do not contend, of course, that Llewellyn denies altogether any creative rôle to law. Though he emphasizes the "power of society over courts," he admits that there is another side to the thing which occasionally manifests itself: "the power of courts over society." [6] He recognizes that sometimes even a single legal decision may shape the growth of an institution,[7] and that men "often do orient the action which they take *apart from* litigation" on the basis of legal rules.[8] Llewellyn himself, then, qualifies the broad statements I have quoted previously. It cannot be asserted that he does not see the whole picture. What I fear is that he may suffer from a species of color blindness which causes him to see one part of the picture with especial vividness while the rest fades into an indistinct background. The aspect of the relation of law and society which he constantly chooses for categorical assertion is "the power of society over courts."

[1] *Bramble Bush* (1930), 12.
[2] *Id.*, at 13.
[3] *Id.*, at 112.
[4] *Id.*, at 113.
[5] Dean Pound has pointed out the similarity between the "juristic pessimism" which the realist movement seems to imply and the views of the historical school and the positivists. Pound, *supra* note 8, at 703.
[6] *Bramble Bush* (1930), 55.
[7] *Ibid.*
[8] *Id.*, at 54.

The qualifications come later, too late to restore a proper balance of emphasis.

This bias on the side of "society" is evidenced in many parts of Llewellyn's work. It is illustrated in his theory that case law will, in a more or less automatic fashion, develop in those places where social change demands it.[1] It is found in his conception of the "pathological case" as the case "so exceptional that the normal ways of society afford . . . no solid basis for deciding [it]. . . ."[2] The implication is that the ordinary, "non-pathological" case can and should find its regulation in the "normal ways of society." The same attitude is found in his discussion of legal certainty. "Layman's legal certainty" is identified with the congruence of law and social norms, and it is assumed, not only that law should generally conform to the "ways of life," but that these ways afford a substantial basis for judicial decision.[3]

This emphasis on the society side of the relation is also found in Llewellyn's constant insistence that the legal scholar's first task must be to master in its last detail the whole pattern of human behavior before he attempts to prescribe regulations for it. This insistence that "value judgments" be postponed until we have traced out exhaustively the whole labyrinth of social norms certainly involves itself a "value judgment," however much Llewellyn may protest the rigid exclusion of "ought" from his approach. If I tell a sculptor that he must spend twenty years investigating the physical and chemical structure of the clay used in modelling before he takes up the study of modelling itself, it will hardly do for me to say I am not teaching sculpture. I shall be judged by the effects of my instructions. The man who has spent most of his life studying clay will be a different kind of sculptor from the man who has devoted more of his time to the art of modelling. There is no *a priori* reason for supposing he will be a better sculptor. If I assume he will be, it must be because of some

[1] Llewellyn, *op. cit.*, *supra* note 5, at 98.
[2] *Id.*, at 82. *Bramble Bush* (1930), 54.
[3] Llewellyn, *op. cit.*, *supra* note 5, at 81.

notion I have concerning the relative importance of clay and modelling in the process of sculpturing.[1]

If I have to choose someone to draft a statute regulating the banking business I may put a high value on a knowledge of banking practice. I may regard as the ideal man for the task the man who knows the practices of the banking world so thoroughly that he can predict with certainty the psychological reactions which the sight of a postdated check will invoke in any banking employee, from messenger boy to president. I may prefer him to a man who, though less familiar with the behavior of bank employees, has spent his life studying the history and theory of banks and banking law, and many hours in arm-chair reflection on the possible ways of organizing and controlling the banking business. I am entitled to my preference. But I am not entitled to escape responsibility for it by saying it involves no "value judgment," no philosophy of what ought to be.

I do not deny that Llewellyn's bias for the society side of the relation may answer to a real need in our law. Lawyers have been too prone to think of society as mere clay in the hands of the "Law." Our courts too often talk as if their task were merely to cut channels, largely after a design of their own fancy, through which the waters of life are expected to flow inertly and complaisantly. To this conception Llewellyn offers a needed antidote. But it is wise to remember that antidotes can be administered too liberally, and that in the case at hand there is danger we may escape one simplification only to fall victims to another.

There are two extreme, and therefore simple, ways of conceiving of the relation of law and society. "Law" can be conceived of as the active principle operating to shape an inert element "society." This is the view toward which the

[1] In his *Cases and Materials on Sales* (1930), XV, n. 3, Llewellyn expresses regret that his book errs "in rarely reaching beyond business practice in the evaluation of legal rules." His defense is that "time for building a wider foundation for judgment has been lacking." This frankness is commendable, and one can only hope that it means that the man who devotes more of his time to "evaluation" and less of it to the investigation of business practice may look forward to being greeted by the realist as a valued co-worker whose efforts supplement his own.

imperative school tends, and it is the view tacitly assumed by most legal writers not of a particularly philosophic turn of mind.

At the other extreme is the view that "society" is the active principle and that "law" is simply a function of this principle. This is the view toward which Maine, Savigny, Ehrlich and Duguit tend. Llewellyn seems to me to place himself in this class, though his closest affinity is with the last two mentioned.

These are the extreme views. Each of them has a value —as a corrective of the other. Indeed it is often difficult to say whether the emphasis made by a given writer is intended to convey his conception of an ultimate truth, or is intended simply to restore a balance which he considers to have been disturbed by extremists on the other side. But fighting fire with fire is always attended by hazards. We avoid the difficulties which arise from these extreme simplistic positions if we recognize frankly that the relation is one of mutual action and reaction. In the relation of law and society neither element is wholly determinative, neither wholly determined. This intermediate view seems to me to represent the position of such scholars as Ihering, Pound, Gény, Stammler and Cohen.

In dealing with this problem we can employ with advantage Cohen's principle of polarity.[1] Law and Society are polar categories. Though we are under the necessity of opposing them to one another we must recognize that each implies the other. If we deny one, the other becomes meaningless. We may picture Law and Society as the two blades of a pair of scissors. If we watch only one blade we may conclude it does all the cutting. Savigny kept his eye on the Society blade and came virtually to deny the existence of the Law blade. With him even the most technical lawyer's law was a kind of glorified folk-way.[2] Austin kept his eye

[1] See Cohen, *Reason and Nature* (1931), 165 *et seq.*

[2] Incidentally it is interesting to note that Savigny's problem here is much the same as that which Llewellyn attempts to dispose of with his notion of the "pathological case." Both start with the assumption that law ought to conform to folk-ways.

on the Law blade and found little occasion in a book of over a thousand pages to discuss the mere "positive morality" which social norms represent. Blackstone shifted his eye from one blade to the other and gave us the confused account in which, on the one hand, he bases the common law on custom, and, on the other, informs us that the authoritative statement of this custom is to be found only in court decisions. As if to add to the confusion, he then lays down rules for determining when a custom should be recognized by the law.[1] We avoid all these difficulties by the simple expedient of recognizing that both blades cut, and that neither can cut without the other.

By saying that we avoid difficulties by adopting the "polar" view of the relation of law and society, I do not mean to imply that the adoption of this view renders the problem a simple one. On the contrary, the advantage of this view lies precisely in the fact that it reveals the difficulties which exist and enables us to prepare to meet them. This view makes it clear that the problem of the relation of law and society is not the sort of issue which can be "solved" by some "theory" and then passed over. It is, to use Radin's suggestive phrase, one of the "permanent problems of the law." But while we may not have disposed of the question, we shall at least have divested it of a specious simplicity which is itself the source of endless difficulty.

The "Institutional Approach" of Underhill Moore

What these difficulties are becomes apparent when an attempt is made to apply in a practical way a simplistic conception of the relation of law and society. One of the most recent and most thorough-going attempts to do this is to be found in Underhill Moore's "institutional approach." Pro-

Both are embarrassed by "technical lawyer's law." What shall we do with it? We not only have it, we also obviously need it. Yet it threatens the theory Savigny's solution of the dilemma was to attempt a specious reconciliation of the fact with the theory. Llewellyn's solution is to isolate the fact so that it may not contaminate the theory as a whole.

[1] 1, *Bl. Comm.*, *38–92. See Bentham's strictures, *A Comment on the Commentaries* (1928), 186 *et seq.*

fessor Moore starts with the question, What actually controls judicial decisions? The judge moves in a complex environment—moral, intellectual, and physical—and his decisions may be regarded as reactions to that environment. But of the numberless factors of this environment, which are the most significant? The traditional theory supposed, or pretended to suppose, that the judge was influenced solely by a segment of his intellectual environment, that represented by "law" and legal theory. This view is no longer tenable. We now realize that rules are impotent to exercise any real control over the judicial process. Even when they seem to chart a definite course (which is seldom because of their vagueness) frequent judicial aberrations from the charted course remind us that there must be other, more significant factors in the judge's environment. Professor Moore then sets about to discover what these more significant factors are. One item after another is rejected. Common sense rejects the assumption that the physical environment has any very important, or at least measurable, influence over judicial decisions. A poorly ventilated court room may conceivably affect the judicial process—but this is a remote and conjectural possibility. The notion that prevailing philosophic notions, conceptions of the good life, may have any very great influence is rejected because these things are matters of "intuition" and are therefore incapable of scientific treatment. The search for some ultimately determinative element begins to look futile. But let us not give up hope. There is one constant in our shifting firmament. We still have the "institutional patterns of behavior" which prevail in the community. We know that "men's actions move along the well-cut channels or straggling ruts of habits"—this is, indeed, "the conclusion of the philosopher, the psychologist and the common man." These folk-ways, these institutional patterns of behavior, become then, like "the sun, the tides, the rain, one of the constant factors among the welter of variables." Can we not assume that the judicial process is controlled by them, that

judicial decisions turn ultimately on the institutional or non-institutional character of the litigants' behavior? [1]

Professor Moore does not rest content with enunciating a theory; he proceeds to test his theory in practice. Do the decisions actually reveal that judges are primarily controlled by the patterns of behavior which prevail in the community? To determine this three cases were selected for study. All three related to the same point of banking law. Two cases (from New York and Pennsylvania) decided the point in one way; [2] the other case (from South Carolina) decided it in another way.[3] Can we explain this difference as arising, not from a different conception of "law," not from a different philosophy of life or from other such imponderables, but from an *observable* difference in the banking practices of South Carolina as compared with those of New York and Pennsylvania? An elaborate investigation was undertaken to answer this question.[4]

[1] This paragraph is intended to summarize the arguments found in "Rational Basis of Legal Institutions" (1923), 23 *Col. L. Rev.*, 609, and "An Institutional Approach to the Law of Commercial Banking" (1929), 38 *Yale L. J.*, 703.

It may be objected at this point that Moore's study is not pertinent to the present inquiry because he clearly disclaims any intent to say what law ought to be. He does not say how courts *ought* to decide cases; he only describes how they *must* decide them. It would be easy to answer this objection by pointing out that it is no unheard of thing for moralists to present their Utopias as necessities, their "oughts" as "musts." But let us give Professor Moore the benefit of the doubt and assume that he is not a preacher disguised as a scientist. His study still remains pertinent to our discussion. Moore is at least disposing of other people's "oughts" whether he is setting up one of his own or not. If courts *must* decide cases by a reference to prevailing behavior patterns, then those who argue that they ought to decide them on some other basis are wasting their breath. For this reason the ethical philosopher cannot avoid bringing Moore into his discussions, however little Moore may feel inclined to return the compliment.

[2] Delano v. Equitable Trust Co., 110 Misc. 704, 181 N. Y. Supp. 852 (1920); Goldstein v. Jefferson Title & Trust Co., 95 Pa. Super. 167 (1928).

[3] Callahan v. Bank of Anderson, 69 S. C. 374, 48 S. E. 293 (1904).

[4] Moore and Sussman, *supra* note 14, a total of 145 pages. The method succeeded in explaining the South Carolina decision, and Moore therefore concludes that "the study probably justifies the inference of a causal relation" between judicial decisions and the institutional or deviational character of the litigants' behavior. *Id.*, at 1249. Aside from the question whether the ability to explain a single decision is a very impressive demonstration of the validity of a method, it is interesting to observe that the South Carolina case was decided by an equally divided court. So while Moore succeeded in explaining why two of the judges voted to affirm the decision of the lower court, he has yet to explain why the other two members of the court voted the other way.

Now before undertaking such an investigation, one has to consider at least four questions. How do you ascertain what social institutions exist, or, to use Moore's own phrase, how do you go about "ethnologizing a particular present day culture"? How do you extract out of the social institutions so ascertained a norm of decision? Can you be sure that the courts will be familiar with existing social institutions and will extract from them the same norm of decision that you do? Can you be sure that the courts will necessarily regard the norm of decision implied in a given social institution as the best one? Moore's study involves an answer to each of these questions and, it seems to me, in each case the answer which he gives is erroneous.

First of all, how do you go about determining what social institutions, what folk-ways, exist? Professor Moore's answer is that you simply observe the way people behave. If you are investigating banking practice with reference to notes, you send an investigator into the cage of the note teller to make a record of what he does. Or, you put a hypothetical situation to an experienced banker and ask him how he would conduct himself in such a case. The emphasis is on behavior. The purpose back of that behavior, the rationalizations and intellectual activity which accompany it are ignored.

This, it seems to me, constitutes the fundamental fallacy of the "institutional approach" of Moore—the assumption that the significance of institutions is exhausted in behavior. In an early article he writes, "To say that a legal institution—private property, the federal government of the United States, Columbia University—exists is to say that a group of persons is doing something, is acting in some way." [1] Now many people would say that a legal institution consists not of actions, but of attitudes of mind to which actions merely give external expression. This view is rejected by Moore on the ground, I take it, that these attitudes of mind are usually simply rationalizations of the behavior which they accompany, and are therefore the effect of the behavior, not the cause

[1] Moore, *supra* note 62, at 609.

of it. *Now it is quite true that this is often the case.* But the truth here happens to be complex, and it is also true that behavior is, at least sometimes, the expression of mental attitudes. This fact is enough to vitiate any purely "behavioristic" approach to social institutions.

Bankers were never asked by Professor Moore's investigators what they were trying to accomplish, or why they acted as they did. They were only "observed," or were asked to state how they would react to certain situations selected by Professor Moore and phrased in his own language. The fallacy of this procedure becomes apparent when we realize that it is impossible to define what the "situation" is to which the banker reacts unless we know what is going on in his mind. We observe that a banker, whose customer's note is due and unpaid, refrains from charging the amount of the note against the customer's checking account until the consent of the customer has been obtained. What is the situation which called forth this reaction? Moore defines the situation entirely in terms of "observables." Was the note secured? How did the note come into the hands of the bank? Had the note just come due, or had it been overdue for some time? Yet from the standpoint of the banker, these were perhaps the least significant elements in the situation. The most significant factor from the standpoint of the banker may have been the fact that the customer's default on the note was obviously due to an oversight, or the fact that the customer was a man of good credit standing, or some other fact not stated in Moore's hypothetical "situation."

The realists regard as one of the fundamental fallacies of the traditional method its assumption that the judge reacts only to those facts of the case which are visible through the prism of legal theory. In truth, the judge's decision represents a reaction to the whole situation, including many facts which from the standpoint of legal theory are irrelevant. The realist condemns the traditional method for its mistaken assumption that you can limit the influence of facts to those

tagged as legally relevant, and for the corollary assumption that it is profitable to discuss the solution of controversies on the basis of textbook outlines of the facts. Yet precisely the same fallacy, if it is a fallacy, is contained in Moore's approach. He adopts toward bankers the same attitude the traditional theory adopts toward judges—a procedure which could only be justified on the doubtful assumption that bankers possess less complicated personalities than judges. He assumes that there are principles guiding the practice of banking which one can discover merely by asking a banker how he would react in certain skeletonized "situations."[1] He seems aware of the temerity of this procedure and of the need for justifying it for he is at pains to report that the answers which bankers gave to his questions were "stated with the positive assurance with which are given descriptions of the way everyday situations are met."[2] This may seem to prove that he had accurately stated the "situations" to which bankers react, but I think that this inference is wholly without justification. If some earnest sociologist were to attempt a "scientific" investigation into the folk-ways of lawyers, and were to ask one hundred unselected lawyers, "Can a man who has rescinded a contract, sue on it?" I suspect that most of his answers would be in the negative and would be given with "positive assurance." The "positive assurance" would exist precisely because the lawyer was asked about a skeletonized, "conceptual" situation. If he were put a series of actual cases his assurance would probably diminish to the vanishing point. Professor Moore asked his bankers if, when a customer's note was due, they charged the note against his account without authority from him. They gave, for the most part, ready answers. Would the answers have been so

[1] [illegible] attitude. I should say that I do not [illegible] skeletonized cases. I think such [illegible] utility. But the "skeletonizing" of [illegible] anticipates the analysis which will be [illegible] That means that when you "skeletonize" situations [illegible] principles on which bankers act in [illegible] This is what Moore made to attempt to do.

[2] [illegible] 14, [illegible]

ready if the situation had been filled out with such pertinent facts as the credit standing of the customer, the availability or nonavailability of legal advice inside the bank, the apparent reason for the customer's default (oversight, insolvency, temporary stringency, *etc.*) and the purpose for which the account was being used? And if not, does the uniformity of the banker's reactions to skeletonized fact situations represent a really significant "institution"?

An uncritical adherence to the behavioristic approach leads to another erroneous assumption, that norms of decision may be extracted directly from regularities of behavior, and that where you have a definite "behavior pattern" you necessarily have a correspondingly definite norm of decision. Now this is demonstrably untrue. It may be the practice of department stores generally to accept goods returned by customers. This behavior pattern may be exemplified in literally thousands of instances. But what norm of decision is implied in this practice? The department store, we shall assume, refuses to accept goods returned by the customer and the customer sues. Now we cannot decide this case simply by referring to the existence of a pattern of behavior. The mere fact that people habitually act in certain ways in certain situations is not itself a criterion on the basis of which law-suits may be decided. If a folk-way is relevant to decision, it must be because it has a "normative" aspect.[1] But we

[1] Moore does not attempt to extract a norm of decision directly out of the behavior patterns which his investigation uncovered. This would have been impossible in view of the behavioristic method pursued in charting these patterns Nevertheless it is obvious that sooner or later it will be necessary to bridge the gap between plain brute fact and sentiments and attitudes which alone can serve as a basis for judicial decision. It is interesting to note how and where Moore makes this transition. His investigation disclosed that the behavior involved in all three cases was "non-institutional"—a result which he had anticipated. Yet obviously this cannot explain why one case was decided in one way and the other two cases in another. This disparity is to be explained by the fact that there was a difference in the *degree* in which the behavior involved deviated from the *nearest institutional pattern*. *Id.*, at 1219. Now two questions arise. What is the nearest institutional pattern? One might have expected that Professor Moore would begin at this point to treat his bank tellers as something other than automata, and he might inquire what patterns *they* would be most likely to regard as offering a precedent for their behavior. But no, our bank tellers remain mere habit complexes, and the "nearest institutional pattern" is determined without any reference to their possible mental processes by a mechanical procedure akin to matching samples of

cannot discover this normative aspect by a mere statistical investigation, by inquiring, in the case I have supposed, how many times department stores have accepted returned goods. We have to discover whether this practice is merely a matter of accommodation ("the customer is always right"), or has established an attitude of expectancy, a sentiment of "ought," which can serve as a norm of decision. The interesting thing is that we can get the most light on this normative aspect of the practice from the way in which the department store acts in what Professor Moore calls "deviational" cases, for example, where the customer's dissatisfaction with the goods is patently unreasonable. The essence of an "institution" will generally be found, not in "behavior," but in mental attitudes, *and frequently the nature of these attitudes is revealed and defined only in "non-institutional" situations. Often it is the observation of behavior in the unusual case which gives definiteness to the contour of an institution.*

cloth. We are now ready to measure the degree of deviation. One might suppose that the same "objective," mathematical method would have been preserved in dealing with this problem. But instead we find that Professor Moore has suddenly endowed his bank tellers with brains, and they are now assumed to act purposively and intelligently. We measure the "degree of deviation" by asking such questions as whether the actual conduct of the parties was as efficient a device for doing business as the institutional pattern, whether it was such a deviation as would be likely to arouse resentment on account of its unfairness—in short, by asking whether the departure was "reasonable" under the circumstances. In the end, then, Moore's method turns out to involve the same intangible elements which are involved in the more conventional approach. The only difference is that in determining "reasonableness" under his method you are forced to take as your standard of comparison what the charts reveal as the nearest institutional pattern of behavior. But after all this limitation is more apparent than real, since the basis on which comparison is made remains vague enough to afford sufficient leeway for the active legal imagination.

Moore's method requires us to answer three questions: (1) what institutional patterns of behavior exist? (2) which of the institutional patterns does the actual behavior of the parties most nearly resemble? (3) how much does the actual conduct of the parties deviate from this pattern? Moore attempts to answer the first two questions on a purely behavioristic basis. In answering the third question the behavioristic approach is abandoned. Moore's study does not, then achieve "objectivity" through the total elimination of "rational" and "intuitive" elements. All it achieves is a postponement of these elements. What is accomplished by that postponement remains unexplained.

Professor Moore has performed a valuable service in calling attention to the need for an actual investigation of lay practices where they are relevant to judicial decision. Courts too often glibly and erroneously assume that they know what these practices are. But Moore's method, as I see it, is fatally defective in its assumption that these practices can profitably be divorced from their "rational" background.

So soon as we abandon the attempt to stick to a purely behavioristic approach, and begin to take into account the intellectual processes which accompany and guide behavior, we see at once the absurdity of the view that the law should (or does) simply take over social institutions as a ready-made norm of decision. We see that our note teller's patterns of behavior may be shaped, not by an invisible psychological force which confines him to some "straggling rut of habit," but by his own imperfect notions of the law, so that to take over his patterns of behavior as a norm of decision is simply to put the judicial ermine on the bank teller and to substitute second-hand knowledge and rumor for the researches of judge and counsel. We see also that "law" and "institutional patterns of behavior" often derive from a common emotional and intellectual source—for example, from current conceptions of business expediency and social justice.[1] For assistance in understanding these intangibles we shall be forced to call back the "brilliant intuitionalists" whom Professor Moore so cavalierly dismissed at the beginning of his study.

Professor Moore claims for his method that it corresponds to the method actually employed by courts, whether they are aware of that fact or not. This necessarily assumes that courts are familiar with the behavior patterns of the community. For the culture patterns of life inside the bank teller's cage can influence the judge only if he knows of them. Yet there seems a certain temerity in the assumption that the

[1] The South Carolina deviation from the rule obtaining in Pennsylvania and New York might conceivably have been explained on the basis of Southern business *mores*. My own experience in the South would lead me to believe that the Southerner does not typically regard the debtor-creditor relationship in the impersonal, "business-like" way it is regarded in the North. It is a personal relation, involving a duty of consideration not only of debtor toward creditor, but of creditor toward debtor. This makes it understandable why a Southern judge would feel a resentment toward a banker who suddenly began turning down his customer's checks, after allowing his note to remain overdue without action for a considerable period. Professor Moore would, of course, scoff at any such explanation as resting on "intuition." But is any more "intuition" involved in this explanation than is involved in his assumption that, in some mysterious way, judges know or "sense" the institutional patterns of behavior prevailing in their communities? But then this assumption probably represents an example of the "qualitative subjective judgment" which Moore admits is involved in his method; it cannot be mere "intuition" for that is presumably excluded from his approach.

justices of the Supreme Court of South Carolina (whose biographies incidentally reveal no practical banking experience [1]) already knew what Moore's investigators took months to learn. Moore meets this point only by saying that the judge's "attitudes and ideas are molded by a cultural matrix whose patterns are engraved by frequency. Put in another way, if the court [the judge?] is not conditioned by frequent contact with the behavior itself, it is conditioned by verbal behavior which will be found, on last analysis, to be causally related to the patterns or institutions." [2] I am not quite sure that I understand this. It seems to mean that the judge in the contacts of daily life will inevitably hear turns of expression which, in some subtle way, will convey to him an insight into what note tellers are doing about debiting direct discounts. But it is hard to believe Professor Moore meant anything quite so preposterous as that. In view of the uncertainty of his meaning, perhaps it would be best to let this point go without refutation.

Let us, then, grant Professor Moore his point about the "cultural matrix," even if we remain a little obscure as to what it is we are granting. Let us assume that there exists a definite pattern of behavior, that the court knows of it, and that the court has been able to extract from it a norm of decision. Still it by no means follows, as Moore seems to assume, that the court will or should regard the norm so obtained as the most desirable basis of decision. Obviously where a court disapproves the end toward which a social practice is directed, it may refuse to accept the practice as a norm of decision. A court may decline to enforce a gambling debt, though it be admitted that the norms of society call for the payment of such debts. Courts exercise at least a veto power over folk-ways. This qualification of the "institutional method" is so obvious that we would be unfair if we did

[1] See Brooks, *South Carolina Bench and Bar* (1908) for biographical sketches of the four justices involved. Incidentally there is nothing in the biographies of the two dissenting judges which would explain why the cultural matrix failed to make an impress on them.

[2] Moore and Sussman, *supra* note 14, at 1219

not assume that the proponents of the method had it tacitly in mind. Let us turn to a less obvious point. Does the institutional method remain valid in those situations where the court regards as innocent the purpose which the parties are attempting to achieve? I think not. To accept the "institutional approach" uncritically even in these cases is to overlook the fact that a court may refuse to conform to a folk-way, not because it disapproves of the object toward which it is directed, but because it considers it ill-adapted to achieve that object. It is to ignore the possibility that a court may undertake to reshape a "behavior pattern" to assist it in reaching its own end. If it were true, for example, that laymen generally regarded the ceremony of "shaking on it" as creating a binding contract, it would not follow that a court would have to accept this ceremony as a valid legal formality if it considered that it offered insufficient safeguards against the dangers which legal formalities are supposed to avert.[1] *The law has always to weigh against the advantages of conforming to life, the advantages of reshaping and clarifying life*, bearing always in mind that its attempts to reshape life may miscarry, or may cost more than they achieve.[2]

Llewellyn does not, I think, carry the behavioristic view as far as it is carried by Moore. He recognizes a qualification on the "institutional approach" which Moore apparently does not—that in many cases law, instead of merely conforming to folk-ways, actually shapes and controls them. Nevertheless he is not, I think, entirely free from the erroneous assumptions

[1] Our courts probably made a mistake in following lay practice in the "liberalization" of the requirement of a seal. In this way they frittered away, perhaps irretrievably, a valuable social practice.

[2] Ihering speaks of the close relation which existed between law and business in ancient Rome. He goes on to say, "The intimacy of the relation between legal science and business redounded to the benefit of both. To the benefit of business, because the lawyer had his hand constantly on its pulse and knew what it needed and how it could be helped. To the benefit of jurisprudence because, without denying in any material respect the demands of business, it could bring business into that form which was, from the legal standpoint, the most desirable one." Ihering, *op. cit.*, *supra* note 13, at 418. American "institutionalists" should, I think, ponder the last sentence, to see whether it may not describe a desideratum they have fallen into the habit of overlooking.

found in Moore's study. I have already expressed the view that he is guilty of at least an error in emphasis. Furthermore there seems to run through his writings the assumption that "law" is only a kind of surrogate for missing folk-ways. In terms of the figure of the scissors, the Law blade only comes into operation when for some reason the Society blade is unable to cut by itself. Indeed, the situation where "the normal ways of society afford . . . no solid basis" of decision and where, accordingly, we must resort to the "law" for solution is quite frankly labelled "pathological." [1] This, it seems to me, clearly implies a behavioristic ethics.

The Emotional Foundations of Realism

The positivistic and behavioristic ethical philosophy of Llewellyn and Moore is found in other realists. In fact it may be said to constitute a strong undercurrent of the realist movement as a whole. Duguit's "positivism," which is another kind of realism, has led him to a similar position. Why should this be? Why should realism, which starts out as a reform movement, carry in its loins this essentially reactionary principle? I think the paradox is explainable.

It is well to remember that the difference between the realist and the "conceptualist" is not so much a matter of specific beliefs as it is of mental constitutions. The conceptualist is not naïve enough to suppose that his principles always realize themselves in practice. Indeed, since he is usually a practical man, he is apt to be more familiar with the specific ways in which life fails to conform to the rules imposed on it than the more philosophic realist. It is not, then, that the conceptualist is ignorant of the discrepancy between Is and Ought. He is simply undisturbed by it.

[1] Llewellyn, *loc. cit.*, *supra* note 56. The attitude of Moore and Llewellyn toward the problem of the relation of law and society may perhaps reveal the distortion which comes from viewing the law from the perspective of one specialty; in their case, commercial law. It is doubtful whether it would occur to a specialist in torts or criminal law to urge a greater *conformity* of law to folk-ways, though such a person would probably go along with Moore and Llewellyn in urging the *relevance* of folk-ways in those fields.

On the other hand, the cleft between Is and Ought causes acute distress to the realist. He sets about resolutely to eliminate it. There are two ways in which this may be done. The Is may be compelled to conform to the Ought, or the Ought may be permitted to acquiesce in the Is. There are enormous difficulties in the first course. Life resists our attempts to subject it to rules; the muddy flow of Being sweeps contemptuously over the barriers of our Ought. There is something even more disheartening. We find it impossible to say exactly what it is we wish life to conform to, what our Ought is. Life laughs at our rules, and even our rules betray us by refusing to reveal their nature to us. The easier course beckons temptingly, to let the Ought acquiesce in the Is, to let law surrender to life.

The realist ends in ambiguity. About one thing he is clear. The disgraceful discrepancy between life and rules must be eliminated. But he is not sure whether his prescription is to force life into conformity with a new, more carefully drawn set of rules, or to permit rules to give way to life. This ambiguity is found in what is perhaps the most ancient formulation of legal realism: *Regula est, quae rem quae est breviter enarrat. Non ex regula ius sumatur, sed ex iure quod est regula fiat.*[1] *Don't get your law from rules, but get your rules from the law that is.* Is this merely a methodological caution, warning us that paper rules often fail to express adequately the principles actually in force? Or does it mean that principles really have no force, and we must get our rules from the "law" of life itself? The clarity of the realist position has not increased perceptibly since the time of Paulus. The modern realist is still not clear in his own mind whether he objects to "conceptualism" because it fails to achieve an accurate formulation of its principles, or because it pretends to proceed according to principle at all.

[1] Paulus in *Dig.*, 50, 17, "De diversis regulis," I.

OBITUARIES

EDWARD SALISBURY DANA

THE death of Edward Salisbury Dana on the sixteenth of last June at the age of eighty-five ended a most remarkable chapter in the history of American science. He was of the third generation of a family that for more than a century and a third guided and enriched our scientific life. The record of this family is unique.

The story may be said to have commenced in 1802 when the elder President Dwight appointed Benjamin Silliman to the professorship of geology, mineralogy and chemistry in Yale College. It was Yale's first recognition of science as a part of the college curriculum. Silliman made two most important contributions to the development of science in the United States. Through his influence the first important mineral collection which came to this country, the Gibbs collection, was brought to New Haven for exhibition and later was purchased by friends of Yale for its permanent use. This collection afforded material for study and early made Yale a center for mineralogical investigation. His second great contribution was the founding in 1818 of the *American Journal of Science*. This, the oldest scientific magazine in the country, was for more than a hundred years edited and supported by the members of the Silliman-Dana family.

James Dwight Dana was a student of Silliman and in time became his scientific successor. These ties were strengthened when he married Silliman's daughter. The elder Dana was perhaps most renowned as a geologist, but it was as a mineralogist that he had his greatest influence on his son Edward's career. J. D. Dana published the first edition of the *System of Mineralogy* in 1837 when only a few years out of college. This book, which has had the greatest influence in that science of any single book published anywhere, passed through five

editions under J. D. Dana's editorship, the fifth edition being dated 1868.

Edward S. Dana was born in New Haven on November 16, 1849, in the house on Hillhouse Avenue where he lived the greater part of his life and in which he died. He graduated from Yale in the class of 1870. The next two years were spent in graduate work, chiefly in mineralogy under the direction of Professor George J. Brush, of the Sheffield Scientific School. The following two years he was abroad, studying at Heidelberg and in Vienna. He returned to New Haven and took his M.A. degree at Yale in 1874 and his Ph.D. in 1876.

There being at that time no opportunity for him to teach mineralogy at Yale he became a tutor in mathematics and physics. In spite of his world-wide reputation as a mineralogist he continued to teach physics and from 1890 until he retired in 1917 he served as professor of physics in Yale College. It should be said that he had a deservedly high reputation as a teacher of physics and even wrote an elementary textbook on mechanics which was widely used for many years.

His real work, however, lay elsewhere. In 1872 he published a paper "On the Composition of the Labradorite Rocks of Waterville, New Hampshire," which is of historical importance, as it was among the earliest reports of an investigation of a rock from the petrographic point of view. His doctor's thesis on "The Trap Rocks of the Connecticut Valley" was the first important memoir using the methods of microscopical petrography to be published in this country. His first paper in mineralogy was published in 1872. In 1876 the remarkable mineral locality at Branchville, Connecticut, was discovered and Professor Brush enlisted Dana's aid in its exploration and the description of its unusual and new minerals. Together they published the five so-called Branchville Papers, the first four between 1878 and 1880 and the fifth ten years later in 1890. These papers contained the descriptions of fourteen minerals, nine of which were at that time new species. Dana furnished the crystallographic and optical

and general physical descriptions, while two younger colleagues, Horace L. Wells and Samuel L. Penfield, made most of the necessary chemical analyses. These papers recorded the most important series of mineralogical investigations that had been made in this country up to that time.

Dana's most important contribution to the advancement of mineralogy, however, was in the books that he wrote. His first volume was the *Textbook of Mineralogy*, the first edition of which was published in 1877. A second edition, entirely revised, was published in 1898 after the appearance of the sixth edition of the *System of Mineralogy*. In the second edition of the text-book appeared chapters on crystallography and the optical properties of minerals, two subjects in which Dana was particularly interested, that were models of clear exposition and which set a standard by which all subsequent treatments have been judged. Two more editions of this book have since appeared.

Dana's greatest achievement, however, was the publication in 1892 of the sixth edition of his father's *System*. There was an interval of nearly twenty-five years between the dates of the fifth and sixth editions. During this period mineralogical investigation was very active and much new material had accumulated. The sixth edition was, therefore, practically a new book. He spent the better part of ten years on its preparation, while at the same time carrying on his teaching and general faculty work, together with many other tasks. It was a heroic undertaking and an extraordinary accomplishment for one man working practically unaided. Not only did the book show great discrimination and rare judgment but an astounding accuracy as well. Mineralogists will bear testimony to the very few errors, even of a typographical kind, that have ever been found in it. It at once established itself as the major reference book in its subject in any language. It is safe to say that references to "Dana" in the mineralogical literature during the last forty years have far exceeded those to any other book. The strain, however, under which Dana worked on this book was so great that his health was

in consequence seriously impaired and his subsequent activities were of necessity much curtailed.

There is no space here to enlarge upon his work in the Yale faculty, where for many years he served upon two important committees. His genial nature and ready tact helped to straighten out many an involved situation. His invaluable services to the Yale Peabody Museum as curator, trustee and finally as chairman of the board of trustees covered a period of many years. Dana became an editor of the *American Journal of Science* in 1875. After the retirement of Silliman in 1885 the two Danas, father and son, carried on as proprietors and editors until the elder Dana's death in 1895. From that date until 1926 Edward Dana was editor-in-chief and was wholly responsible for its publication. At that time the journal was transferred to Yale University and other men have since served as editors, but up to his death Dana took an active interest in its affairs. Because of his wide interest in and knowledge of diverse scientific fields, Dana was able to fill its pages with a long series of important articles and to maintain its high standard as a general scientific journal.

Dana's was a most charming and genial personality. He had a ready smile and a quiet humor. He was always most interested in what other people were doing and always helpful in his advice. It was always difficult to get him to talk about himself, for his was a true modesty. He was generous to a fault, of time and of money. No one knows the extent of his private benefactions. Many people could testify to his helpful encouragement. One instance may perhaps be cited as typical of many others. A young high-school boy in Texas became interested in minerals and wrote a letter to Professor Dana asking advice. Dana, already then eighty years old, at once entered into a lively correspondence with the lad, sending him books and mineral specimens and doing all he could to encourage the boy's scientific interest. When the young man graduated from his school he asked as his graduation present enough money to enable him to travel east and

to go to New Haven and pay his respects to his old friend. It was a tribute that must have warmed Dana's heart.

Another typical instance of unselfish service must be related. After the war some of the older mineralogists and their families living in Vienna were in desperate circumstances. Recalling his student days in that city, Dana on his own initiative solicited small contributions from American mineralogists and transmitted the funds thus obtained to Vienna. He continued this self-imposed task until the end. The Vienna Academy sent this greeting to him on the occasion of his eightieth birthday:

> We recognize you as the master and leader of American mineralogists, and we of Vienna may rightfully claim Edward S. Dana as one of ourselves. Since 1873 bonds of personal friendship have been formed between you and a number of physicists and mineralogists in Vienna. . . . With this circle of friends you have kept faith during one of the saddest times which Vienna and Austria have ever experienced. When the State was finally unable to protect Austrian scholars of world-wide fame and their families from bitter need, you have remembered your friends and with the courage of a kind heart, have been one of the first to collect funds for their support. We all think of you with lasting gratitude.

That in itself alone forms a monument that will endure.

William E. Ford[1]

EDWIN BRANT FROST
1866–1935

Edwin Brant Frost was born on July 14, 1866, at Brattleboro, Vermont. It was here or in the immediate neighborhood that most of his forbears for several generations had lived and flourished. The first of the name in this country was Edmund Frost, who came to Boston in 1634. Edwin was the second son of Carleton Pennington Frost (1830–96), who practiced medicine in Brattleboro and neighboring towns until 1871, when he moved with his family to Hanover, New Hampshire, there to be a professor in the Dartmouth Medical School and afterwards dean of the school and a trustee of the college.

[1] Abstract from *Science*.

Edwin was graduated A.B. at Dartmouth in 1886. The year following he continued postgraduate work at Dartmouth, taught school in a nearby village and at the end of the year spent a few months at Princeton, where he came under the influence of Charles Augustus Young (1834–1908). Three years later he secured a two-years leave to visit most of the European observatories and to spend a year at Potsdam in Germany, where Vogel was establishing an observatory devoted especially to the new science of astrophysics and where he had gathered around him an exceptionally brilliant staff. Frost thus had an opportunity to come into contact with a group that it would have been difficult to match at a single institution either in that day or during the twenty years to follow. When he returned to Dartmouth in 1892 it was as assistant professor, and this promotion was followed in 1895 (when he was only twenty-nine years of age) by a full professorship and the directorship of the Dartmouth Observatory.

While at Potsdam Frost made arrangements with Scheiner to translate into English the latter's *Spectralanalyse der Gestirne* (1891). Frost's translation played an important part in the rapid development of the science in this country, and until very recently it remained the standard work on the subject in our language.

In 1897, Dr. George E. Hale, director of the recently completed Yerkes Observatory at Williams Bay, Wisconsin, successfully applied to Miss Bruce for a grant sufficient to set on foot an extensive program of spectroscopic observations of the stars. It was under these auspices that Professor Frost took up his duties at Williams Bay in the summer of 1898, expecting to stay for five years only. But before the end of this term Hale had organized what was at first an expedition from the Yerkes Observatory to California to observe the sun under more favorable climatic conditions. As every one knows, this expedition grew into the Mount Wilson Observatory. In the two years following 1903 much of the responsibility for the conduct of the Yerkes Observatory fell to Frost. On Hale's resignation as director in 1905, Frost was appointed to succeed him in June of that year.

Frost was distinctly a specialist devoting his energies to the spectroscopy of "early-type" stars to the practical exclusion of every other subject. Primarily for this purpose the Bruce spectrograph was constructed in 1900 largely from his specifications and under his supervision. With this instrument he measured the radial velocities of many B-type stars and discovered their most important characteristics. It was shown that their velocities are small as compared with those of later-type stars and that there is a slight but unmistakable tendency for these stars to recede from our system as a whole, as if they formed an expanding group. These facts were later more fully developed by Campbell.

Frost also showed from changes in radial velocity that a surprising number of B-type stars are close binary systems, perhaps as many as one in every three. On several occasions I have witnessed his discovery of such a binary from a single photograph of its spectrum. This sounds like an impossibility, but the explanation is simple. Even in those days (around 1904) he was extremely nearsighted, and could see well an object not more than an inch from his eye; thus, as he used to say, by simply pushing his glasses up he always had at his disposal a magnifying power of about ten diameters. After he had secured a spectrogram and developed it the next morning, he would examine it in this way, sometimes before it was dry. If he saw the lines considerably displaced from their normal positions, he knew that it was extremely unlikely that this was because of the star's large space velocity, since, as we have said, he had found that such velocities are always small for B-type stars; the displacements must then be due to orbital motion, and so indeed they invariably proved to be when later he could examine a series of plates of that star.

Frost's place in astronomy is not to be judged on the basis of his researches alone. We have already mentioned his translation of Scheiner's work and the part this translation played. For more than thirty years his was the chief responsibility for editing the *Astrophysical Journal*, "an inter-

national review of spectroscopy and astronomical physics," founded in 1895 by Hale and Keeler, and now in its eighty-first semi-annual volume. One might say of Frost as Frost used to say of Burnham, "he is the best skeptic I know." As a result of this quality of judicious conservatism, the *Astrophysical Journal* has had little to regret in the way of hasty or ill-advised publication. In addition, he had an unusually sensitive feeling for language.

The last years of his life form a sad story, but an inspiring one as well. From early childhood he had had trouble with his eyes. This became acute by 1907 and necessitated long periods of complete rest for his eyes. In 1915 the retina in one eye became detached and within a few months he completely lost the sight in this eye, never to regain it. A few years later a cataract began to form in his other eye and grew worse and worse until he became totally blind. In spite of this heavy handicap, he managed for several years to continue his work as director of the observatory, but finally felt compelled to retire in 1933. In all his years of complete darkness he never lost his sense of humor. To the last he had a way of ignoring his blindness in conversation and whimsically using terms and expressions that one should ordinarily expect only from those who can see.

He lived to enjoy his retirement less than two years, dying on May 12, 1935, after an operation for gallstones.

He was elected a member of the American Philosophical Society in 1909. Among other honors that came to him were degrees from Dartmouth and Cambridge; membership in the National Academy of Sciences and in the American Academy of Arts and Sciences; honorary membership in astronomical societies in England, Italy, Mexico, Canada, and Russia.

Frost was married in 1896 to Mary Hazard of Boston; she and her three children survive him.

FRANK SCHLESINGER

THOMAS McCRAE

THOMAS McCRAE, Professor of Medicine in the Jefferson Medical College, died in Philadelphia June 30, 1935, aged 64 years. He was born at Guelph, Ontario, December 16, 1870, the son of Lt. Col. David McCrae and Janet Eckford McCrae. His brother, Lt. Col. John McCrae, was the celebrated poet-author of "Flanders Field." Dr. McCrae was an undergraduate and medical student at the University of Toronto, where he received the degree of A.B. in 1891, M.B. in 1895, and M.D. in 1903. In 1927 his Alma Mater conferred on him the honorary degree of Sc.D. In 1901 he achieved membership in the Royal College of Physicians of London (England) and in 1907 Fellowship in the same College.

After his graduation in Medicine he served as an Interne in the Toronto General Hospital and thereafter became Resident Physician and later Associate Professor at Johns Hopkins under William Osler.

In 1912 he was called to Jefferson Medical College as Professor of Medicine, in succession to Professor James C. Wilson. He held this position and fulfilled its duties with great zeal and ability to the end of his life. In addition to his membership in the American Philosophical Society, he was a member or fellow in numerous medical organizations, notably the Association of American Physicians of which he was Secretary from 1917 to 1926 and President in 1930, the College of Physicians of Philadelphia and the Association of Physicians of Great Britain and Ireland.

He was a voluminous writer of medical books and journal articles, and collaborated with William Osler as joint editor of "Modern Medicine," a seven volume cyclopedia, and "Osler's Principles and Practice of Medicine." Aside from technical writing he was keenly interested in medical history and wrote a number of important biographical papers in this field. In 1924 he delivered the Lumlein Lectures at the Royal College of Physicians in London.

Dr. McCrae was universally esteemed by his professional colleagues as a skilled physician, a cultured gentleman and a man of the widest intellectual interests.

ALFRED STENGEL

WILLIAM WALLACE ATTERBURY

THE death of General W. W. Atterbury, September 20, 1935, takes from the American Philosophical Society a member of outstanding ability as an engineer and railroad executive. For forty-nine years he had served the Pennsylvania Railroad Company rising from a shop apprentice to the presidency of a railroad system having more traffic than any other system in the world. His membership in the Philosophical Society dates from 1916.

General Atterbury was born in New Albany, Indiana, January 31, 1866, but he lived in Detroit, Michigan, during his boyhood. He graduated from Yale University with a Ph.B. degree in 1886, and in October of that year entered the Pennsylvania Railroad shops at Altoona as apprentice. As would be expected, his ability and personality caused him to be called each few years to a position of greater responsibility. During the three years from 1889 to 1892, he was assistant road foreman of engines on different divisions of the Pennsylvania Railroad; in 1892 he became assistant engineer of motive power of the Pennsylvania system of roads northwest of Pittsburgh; and from 1893 to the latter part of 1896 he served as master mechanic for the Pennsylvania at Fort Wayne, Indiana. Then for five years he was the superintendent of motive power of the Pennsylvania Railroad, his headquarters being at Altoona, Pennsylvania; and in 1901, at the end of only fifteen years of service, he was appointed general superintendent of motive power of the Pennsylvania Lines east of Pittsburgh and Erie in which position he served but fifteen months when he was transferred to the transportation department of the railroad and given the position of general manager of the lines east of Pittsburgh and Erie. Six years later, in 1909, he became vice-president in charge of transportation, and in 1912 he was given the title of vice-

president in charge of operation, having, under a reorganization of the directorate, become one of the directors of the Company in 1911.

It was the public services rendered by General Atterbury during the World War that made him nationally known. At the request of Newton D. Baker, Secretary of War, General Atterbury went to France, in August 1917, to serve as director general of transportation of the American Expeditionary Forces. He was commissioned a brigadier-general; and the part he played in organizing the transportation of American troops and military supplies in France was of such assistance to the Allies that upon his return to the United States, at the end of May 1919, the United States awarded him the distinguished service medal, France made him a commander of the Legion of Honor, Great Britain gave him the rank of Commander of the Most Honorable Order of the Bath, and Belgium made him a Commander of the Order of the Crown.

Upon his return General Atterbury resumed his work as a vice-president in charge of operation of the Pennsylvania Railroad, and with jurisdiction over the entire system. In November 1920, he was chosen vice-president without designation, in order that he might share the executive burdens of the president; and when Mr. Samuel Rea retired from the presidency, October 1, 1925, General Atterbury was selected to fill the vacancy. During the eight and three quarter years of his presidency, he inaugurated and carried out numerous large works, the principal one being the electrification of the Pennsylvania Railroad from New York to Washington. His business activities also included membership in the directorates of several financial institutions.

In recognition of his services as engineer, railroad executive and government official, General Atterbury was made an honorary member of the American Society of Mechanical Engineers, and was awarded the honorary degree of LL.D. by the University of Pennsylvania in 1919, by Yale University in 1926, by Villa Nova College in 1927, and by Temple University in 1929.

Emory R. Johnson

HUGO DE VRIES

Hugo de Vries, one of the most distinguished members of the American Philosophical Society, died at his home in Lunteren, Holland, on May 21, 1935. He was 87 years of age. To the last, he was actively engaged in genetical research, his last scientific article appearing some months after his death.

Born on February 16, 1848, of distinguished and scholarly parents, de Vries early developed an interest in the science of botany, which he pursued with notable success at the Universities of Leiden, Heidelberg and Würzburg. In 1877 he became Privatdozent at the University of Halle, and later in the same year accepted an appointment as lecturer in Plant Physiology in the University of Amsterdam, where he remained for the next 40 years. For 32 years, he was Professor and Director of the Botanical Institute and Garden of this institution.

Professor de Vries was three times in the United States, delivering lectures at the University of California, and at other important universities and research institutions. The honors conferred upon him were numerous, including honorary, corresponding or foreign membership in most of the leading scientific academies of the world, and honorary degrees from many institutions. His published writings include a number of important books, and numerous scientific articles; most of the latter are now available in collected form, occupying 7 large volumes. His chief books were: *Intracellular Pangenesis*, 1889; *Die Mutationstheorie*, 1901 and 1903; *Species and Varieties, their Origin by Mutation*, 1905; *Gruppenweise Artbildung*, 1913.

De Vries' chief contributions were in the fields of plant physiology and genetics. As a young man he began an intensive study of turgor phenomena in plant cells, passing thence to an investigation of the osmotic properties of living membranes. In this connection, he developed the plasmolytic method for the determination of osmotic values, the utiliza-

tion of which led to his discovery of the fundamental facts upon which rest van't Hoff's famous generalization, and Arhennius' formulation of the theory of electrolytic dissociation.

While these investigations were in progress, de Vries was also actively interested in the problem of the origin of species. He found it difficult to accept the then current Darwinian conception that species have arisen through the gradual accumulation of minute variations, because of the fact that a process of this sort would be difficult, if not impossible to observe directly. de Vries felt the need of accurate factual information with regard to the appearance of genetic modifications, and set out to study the nature of variations, utilizing a variety of approaches. These researches, extending over the greater part of his active career, resulted in the accumulation of much valuable information, and the formulation of important concepts. Among the more significant results should be mentioned the following: (1) The Theory of Intracellular Pangenesis, a modification of Darwin's Pangenesis Theory, which foreshadowed in large measure the modern concept of the gene. (2) An analysis of the numerical relations which exist between the various classes in the offspring of hybrids, an analysis which, unknown to de Vries, had previously been made by Mendel. Incidentally, de Vries was one of the three botanists who later independently re-discovered Mendel's work and brought it to the attention of students of heredity. (3) The celebrated Mutation Theory of Evolution, which has had such a profound influence on biological thinking during the past third of a century. This theory was largely based upon the anomalous behavior of certain races of Œnothera (the evening primrose), a genus of plants which was first investigated by him, and which has yielded many facts of great importance to genetics and cytology.

Few biologists have exercised as profound an influence in as many fields as has de Vries. In the field of bio-physics, his researches paved the way for other important generaliza-

tions of van't Hoff and Arhennius. In the fields of genetics and evolution, his investigations laid the ground-work for our present-day concept of the gene, and for the degree of understanding which we now possess of the nature of the heritable variations which form the building blocks of evolution. Significant as were his own researches, however, they were probably of less importance on the whole, than was his insistence upon accurate and extensive observation, and controlled experimentation, as the necessary basis for all scientific postulates. He began his work in an era when students of evolution were prone to speculate upon the basis of an insufficient body of fact. He probably did more than any other single individual to usher in an era of intensive experimentation, and hence of rapid progress in the fields of genetics and evolution.

Ralph E. Cleland

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THE SPLIT CYLINDRICAL CONDENSER I

E. P. ADAMS

(*Read by title, April 25, 1936*)

1. THE FIRST problem considered in this paper is that of a circular cylindrical shell from which the portion between two planes parallel to the axis, and equidistant from it, has been removed. The two equal conductors thus formed may have equal and opposite charges and so form the plates of a condenser. But we shall consider the more general problem of the two conductors with any given charges. Then the problem of the condenser will be a special case of the general solution.

The method to be used is one that has been described in previous papers in these *Proceedings*.[1] Fig. 1 shows the

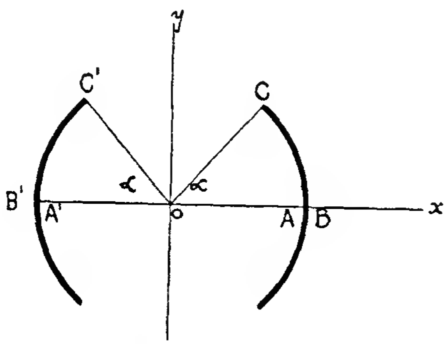

Fig. 1

z-plane, that of any plane perpendicular to the axis of the cylinder. The two conductors are shown as arcs of a circle of radius a. However the conductors are charged, the x-axis is one of symmetry, and so we need consider only the portion of the z-plane lying above this axis. We first transform from

[1] LXXV, pp. 11, 549, 1935.

the z-plane to the w-plane by means of the equation,

$$w = u + iv = \log z/c = \log r/c + i\theta, \qquad (1)$$

so that

$$u = \log r/c, \qquad v = \theta.$$

The w-plane is shown in fig. 2. In order to transform the

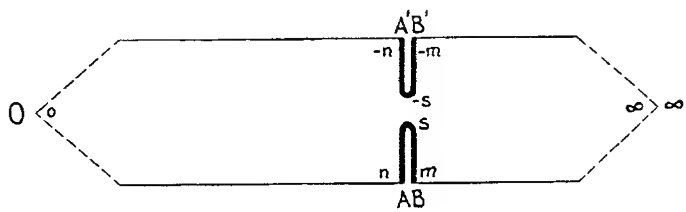

Fig 2

w-plane to the upper half of the t-plane, we choose real values of t to correspond to the corners of the polygon in the w-plane according to the scheme:

$$\infty > m > s > n > 0 > -n > -s > -m > -\infty.$$

s and $-s$ correspond to the edges C and C' of the two conductors. The Schwarz-Christoffel differential equation is

$$\frac{dw}{dt} = \frac{A(t^2 - s^2)}{t\{t^2 - m^2 \cdot t^2 - n^2\}^{\frac{1}{2}}}. \qquad (2)$$

The jump in w at $t = 0$ is $-i\pi$ and at $t = \infty$ it is $i\pi$. So we find $A = 1$. The solution of (2) may be written

$$w = \log \frac{(t^2 - m^2)^{\frac{1}{2}} + (t^2 - n^2)^{\frac{1}{2}}}{(m^2 - n^2)^{\frac{1}{2}}} - \frac{s^2}{mn} \log \frac{n(t^2 - m^2)^{\frac{1}{2}} + m(t^2 - n^2)^{\frac{1}{2}}}{t(m^2 - n^2)^{\frac{1}{2}}} + B. \qquad (3)$$

To determine the constants we have the scheme

$t =$	m	n	$-n$	$-m$
$w =$	$\log a/c$	$\log a/c$	$\log a/c + i\pi$	$\log a/c + i\pi.$

When these values are substituted in (3) we find

$$s^2 = mn,$$
$$B = \log a/c.$$

We can choose $mn = 1$, and then $s = \pm 1$ corresponds to the edges of the conductors. We can now write (3)

$$\frac{r}{at}e^{i\theta} = \frac{m(t^2 - m^2)^{\frac{1}{2}} + (m^2t^2 - 1)^{\frac{1}{2}}}{(t^2 - m^2)^{\frac{1}{2}} + m(m^2t^2 - 1)^{\frac{1}{2}}}. \tag{4}$$

On the circular arc ACB, $r = a$ and $n \leq t \leq m$. So we find

$$\cos\theta = \frac{m(t^2 + 1)}{t(m^2 + 1)}. \tag{5}$$

This gives the relation between t and θ on the arc. Since t and $1/t$ give the same value for θ, values of t greater than unity correspond to the convex side and values of t less than unity to the concave side of the arc. If 2α is the angle subtended by the whole arc at the center, we get

$$\cos\alpha = \frac{2m}{m^2 + 1},$$

and

$$m = \frac{1 + \sin\alpha}{\cos\alpha}. \tag{6}$$

2. We next consider the χ-plane, χ being the complex potential, $\chi = \phi + i\psi$, with ϕ as the real potential. The χ-plane is shown in fig. 3 for the case in which the right-hand

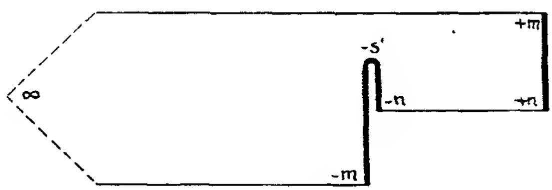

Fig. 3.

shell has a charge Q_1 on unit length, at potential V, and the left-hand shell a charge Q_2 at potential 0. It is assumed that

$Q_1 + Q_2$ is positive so that lines of force go out to infinity where the potential is taken to be $-\infty$. $t = -s'$ corresponds to a point of equilibrium. Although it is shown upon the left-hand shell, its position will depend upon the relative charges of the two conductors and will be determined by the solution of the problem. The differential equation for the transformation to the t-plane is

$$\frac{d\chi}{dt} = \frac{C(t + s')}{\{t^2 - m^2 \cdot t^2 - n^2\}^{\frac{1}{2}}}. \tag{7}$$

Since there is a jump of $-2\pi i(Q_1 + Q_2)$ in χ when t passes from $+\infty$ to $-\infty$, we find $C = -2(Q_1 + Q_2)$.

The solution of (7) is

$$\chi = iC \sin^{-1}\left\{\frac{m^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} - \frac{Cs'}{m}\lambda + D,$$

where $t = n\,sn\,\lambda$, with the modulus

$$k = n/m = 1/m^2. \tag{8}$$

To determine the constants we have the scheme,

$t =$	m	n	$-n$	$-m$
$\lambda =$	$K + iK'$	K	$-K$	$-K + iK'$
$\chi =$	$V + 2\pi i(Q_1 + Q_2)$	$V + 2\pi i Q_2$	$2\pi i Q_2$	0.

On substituting in the solution we find

$$V = 2\pi(Q_1 - Q_2)\frac{K}{K'}, \tag{9}$$

and

$$\frac{s'}{m} = \frac{\pi}{2K'}\frac{Q_1 - Q_2}{Q_1 + Q_2}. \tag{10}$$

From (9) we find for the capacity of the condenser formed of the two cylindrical shells, obtained by putting $Q_1 + Q_2 = 0$,

$$S = \frac{K'}{4\pi K}. \tag{11}$$

This may be determined as soon as the modular angle,

$\sin^{-1} k$, is known. From (6) and (8) we get

$$k = \frac{1 - \sin \alpha}{1 + \sin \alpha}, \tag{12}$$

or

$$\sin \alpha = \frac{1 - k}{1 + k}. \tag{13}$$

It therefore follows that the capacity of such a condenser is completely determined by the angle α, being independent of the radius of the cylinder of which the shells form a part. This result can easily be seen from a consideration of dimensions. The capacity of a unit length of the condenser is a dimensionless quantity and so can depend only on the ratio of two lengths. Now the only lengths involved are the radius and the length of the arc. But the ratio of these two lengths is the angle 2α, and so the capacity is determined by this angle and is independent of the radius. The capacity may be expressed in terms of the q-function, defined by

$$q = e^{-\frac{\pi K'}{K}}.$$

From (11) we get

$$S = \frac{1}{4\pi^2} \log \frac{1}{q}.$$

The complex potential for the general case may be written,

$$\chi = -2i(Q_1 + Q_2)\left(\sin^{-1}\frac{dn\,\lambda}{k'} - \pi\right) + \frac{\pi(Q_1 - Q_2)}{K'}(\lambda + K - iK'). \tag{14}$$

For positive values of t we must use that value of the inverse sine that is less than $\pi/2$, and for negative values of t that value of the inverse sine that lies between π and $\pi/2$. At the edge of the shell, $t = 1$, and so for this point

$$sn\,\lambda = k^{-\frac{1}{2}}.$$

Accordingly,

$$\lambda = K + \tfrac{1}{2}iK'.$$

The values of ψ at the three points A, C, B are now given by

$$\psi_1 = 2\pi Q_2,$$

$$\psi_2 = 2(Q_1 + Q_2)(\pi - \sin^{-1}(1 + k)^{-\frac{1}{2}}) - \frac{\pi}{2}(Q_1 - Q_2),$$

$$\psi_3 = 2\pi(Q_1 + Q_2).$$

When the two conductors form a condenser so that $Q_1 + Q_2 = 0$, we get for the charge on the convex portion of the positive shell,

$$\frac{1}{2\pi}(\psi_3 - \psi_2) = \tfrac{1}{2}Q_1,$$

and on the concave side the charge is

$$\frac{1}{2\pi}(\psi_2 - \psi_1) = \tfrac{1}{2}Q_1.$$

Thus the whole charge is equally divided between the convex and concave sides. If the two conductors are at the same potential, so that $Q_1 = Q_2 = Q$, we find for the charge on the convex side of one shell

$$\frac{1}{2\pi}(\psi_3 - \psi_2) = \frac{2Q}{\pi}\sin^{-1}(1 + k)^{\frac{1}{2}},$$

and the charge on the concave side is

$$\frac{1}{2\pi}(\psi_2 - \psi_1) = Q\left\{1 - \frac{2}{\pi}\sin^{-1}(1 + k)^{-\frac{1}{2}}\right\}.$$

The electric intensity at any point is given by

$$R = \left|\frac{d\chi}{dz}\right|,$$

and the surface density, σ, at any point of a conductor, by

$$4\pi\sigma = R.$$

We find for the surface density on the convex side of the right-hand shell

$$\sigma_1 = \frac{t}{2\pi a(t^2 - 1)}\left\{(Q_1 + Q_2)t + \frac{1}{2}\frac{\pi}{k^{\frac{1}{2}}K'}(Q_1 - Q_2)\right\},$$

and on the concave side, where t is less than unity,

$$\sigma_2 = \frac{t}{2\pi a(1 - t^2)} \left\{ (Q_1 + Q_2)t + \frac{1}{2} \frac{\pi}{k^{\frac{1}{2}} K'} (Q_1 - Q_2) \right\}.$$

Both of these expressions are infinite at the edge where $t = 1$. The relation between t and θ, the angle fixing the position of the point on the conductor, is given by (5).

3. We shall now find the charges induced upon the two cylindrical shells when they are placed in a uniform electric field; we first suppose that this field is along the negative x-axis, so that the potential due to it is Fx, F being the intensity of the field at infinity. We shall assume that there is a difference of potential, V, between the two shells, and that these have any charges, Q_1 and Q_2. We shall therefore assume that the shell on the left has a charge Q_2 and is at potential 0, while that on the right has a charge Q_1 and is at potential V. The induced charges are included in Q_1 and Q_2. A special case of this general problem enables us to find the shielding effect of such a system. The differential equation for the transformation from the χ- to the t-plane is now

$$\frac{d\chi}{dt} = C \frac{(t - s')(t + s'')}{\{t^2 - m^2 \cdot t^2 - n^2\}^{\frac{1}{2}}}. \qquad (15)$$

s' and s'' are the real values of t that correspond to the points of equilibrium. Whether they are on the conductors or on the x-axis will of course depend upon the electrical state of the system.

The solution of (15) subject to the conditions,

$$\begin{array}{lllll} t = & m & n & -n & -m \\ \chi = & V + 2\pi i(Q_1 + Q_2) & V + 2\pi i Q_2 & 2\pi i Q_2 & 0, \end{array}$$

is

$$\chi = CmZ(\lambda) + \frac{V}{2K}\lambda - 2i(Q_1 + Q_2) \sin^{-1}\frac{dn\,\lambda}{k'} + \tfrac{1}{2}V + i\pi(Q_1 + 3Q_2). \quad (16)$$

In this, λ is again defined by $t = n\, sn\, \lambda$, with $k = n/m = 1/m^2$,

and s' and s'' are given by the two equations

$$\frac{s' - s''}{m} = \frac{2\pi(Q_1 + Q_2)}{K\left\{\frac{K'V}{\pi} - 2\pi(Q_1 - Q_2)\right\}}, \tag{17}$$

$$\frac{s's''}{m^2} = \left(1 - \frac{E}{K}\right) + \frac{V}{2mCK}. \tag{18}$$

The constant C is given by

$$C = \frac{Kk^{\frac{1}{2}}}{\pi}\left\{\frac{K'V}{\pi} - 2\pi(Q_1 - Q_2)\right\},$$

and must be determined so as to make the field at infinity equal to F. Now we have

$$\frac{d\chi}{dz} = -X + iY = C\frac{t - s' \cdot t + s''}{t^2 - 1} \cdot \frac{t}{z}, \tag{19}$$

where X, Y are the x and y components of the electric force. At infinity both t and z are infinite. From (4) we find that as t and r approach infinity the limiting value of t/r is

$$\text{Limit } t/r = \frac{m^2 + 1}{2ma} e^{i\theta}.$$

In order, therefore, that the field at infinity be F in the direction of the negative x-axis we must have

$$C = \frac{2amF}{m^2 + 1} = \frac{2ak^{\frac{1}{2}}F}{1 + k}. \tag{20}$$

Let us now suppose that the two conductors are at the same potential, so that $V = 0$, and that their only charges are those induced by the field. We must then have $Q_1 = -Q_2 = -Q$. From (17) we get $s' = s''$, and from (18),

$$s'^2 = s''^2 = \frac{1}{k}\left(1 - \frac{E}{K}\right).$$

As the term on the right is always less than $n = k^{\frac{1}{2}}$, it follows that the two points of equilibrium are on the x-axis between the shells, one on each side of the origin. The value of χ for

this case reduces to

$$\chi = 4KQZ(\lambda) + 2\pi iQ.$$

$-Q$ is the charge induced on the right-hand shell and is given by

$$Q = \frac{aF}{2K(1 + k)}\cdot$$

At the edge of the shell, $t = 1$, $\lambda = K + \frac{1}{2}iK'$. Since

$$Z(K + \tfrac{1}{2}iK') = \tfrac{1}{2}i(1 - k) - i\frac{\pi}{4K},$$

we get for the value of ψ at the edge,

$$\psi = \pi Q\left\{1 + \frac{2}{\pi}(1 - k)K\right\};$$

and since the value of ψ is 0 at the center of the shell on the convex side, the charge induced on the convex side of the shell is

$$-\tfrac{1}{2}Q\left\{1 + \frac{2}{\pi}K(1 - k)\right\}.$$

So for a very small modular angle, when α is nearly $\pi/2$ and K is nearly $\pi/2$, nearly all the induced charge is on the convex side of the shell.

The shielding effect produced by the two shells can now be examined. For this purpose we need to calculate the electric intensity at points inside the circle of radius a. Along the x-axis t is real and ranges in value from 0 at the origin to $\pm k^{\frac{1}{2}}$ at the surface. The electric intensity is given by (19). At the centre, where t and z are zero, we have by (4),

$$\frac{t}{x} = \frac{2k^{\frac{1}{2}}}{(1 + k)a},$$

and so the field at this point is given by

$$X = -\frac{4F}{(1 + k)^2}\left(1 - \frac{E}{K}\right).$$

For small modular angles, E/K is nearly unity, and so the

field at the centre is very small. At the surface of the shell itself, where $t = k^{\frac{1}{2}}$, for the shell on the positive side,

$$X = \frac{2F}{k'^2}\left(\frac{E}{K} - k'^2\right)$$

in the positive direction. Between these two points there is a point of equilibrium, corresponding to $t = s'$, and another on the negative axis, corresponding to $t = -s'$.

The values of t corresponding to points on the y-axis are pure imaginary. Let us put $t = i\eta$ on the positive y-axis. Then we get from (19),

$$-X = \frac{2k^{\frac{1}{2}}F(\eta^2 + s'^2)}{(1 + \eta^2)(1 + k)^2}\frac{a\eta}{y},$$

and the values of y and η are connected by the equation

$$\frac{a\eta}{y} = \frac{k^{\frac{1}{2}}(1 - \eta^2) + (k + \eta^2)^{\frac{1}{2}}(1 + k\eta^2)^{\frac{1}{2}}}{1 + k}.$$

When $\eta = 1$, $y = a$, and we find

$$X = -\frac{F}{k^{\frac{1}{2}}(1 + k)}\left(1 + k - \frac{E}{K}\right).$$

For a modular angle of 1°, corresponding to an angle $\alpha = 75°$ approximately, we find

$$X = -0.131F.$$

4. When the external field at infinity is along the y-axis, the χ-plane is simply the t-plane turned through a right angle. We can therefore write

$$\chi = iC't.$$

When t approaches infinity, we get from (4)

$$\frac{x + iy}{at} = \frac{2m}{1 + m^2} = \frac{2k^{\frac{1}{2}}}{1 + k},$$

and so

$$t = \frac{(1 + k)(x + iy)}{2ak^{\frac{1}{2}}}.$$

It therefore follows that at infinity,

$$\chi = \varphi + i\psi = \frac{iC'(1 + k)}{2ak^{\frac{1}{2}}}(x + iy).$$

If the potential at infinity is to be Fy we must therefore have

$$C' = -\frac{2aFk^{\frac{1}{2}}}{1 + k}.$$

The values of ψ at the points B, C, and A, corresponding to $t = m$, l, and n, are now given by

$$\psi_1 = -\frac{2aF}{1 + k},$$

$$\psi_2 = -\frac{2aFk^{\frac{1}{2}}}{1 + k},$$

$$\psi_3 = -\frac{2aFk}{1 + k}.$$

If $\pm Q$ are the equal and opposite charges induced on either shell, we find

$$Q = -\frac{aF}{2\pi}\frac{1 - k}{1 + k} = -\frac{aF}{2\pi}\sin\alpha.$$

The equal and opposite charges induced on the convex side of either shell are given by

$$Q' = -\frac{aF}{2\pi}\frac{1 - k^{\frac{1}{2}}}{1 + k}.$$

For small modular angles, when α is nearly $\pi/2$, this is almost the whole induced charge.

The electric intensity at any point is given by

$$\frac{d\chi}{dz} = -X + iY = -i\frac{2aFk^{\frac{1}{2}}}{1 + k}\{t^2 - m^2 \cdot t^2 - n^2\}^{\frac{1}{2}}\frac{t}{z}.$$

At the origin, where $t = 0$, we get

$$Y = -\frac{4Fk}{(1 + k)^2}.$$

At $t = i$, where $r = a$, $\theta = \pi/2$, we find

$$Y = -F.$$

5. A problem similar to the one that has just been solved is that of a cylindrical conductor partly surrounded by a coaxial cylindrical shell. The z-plane is shown in fig. 4, and

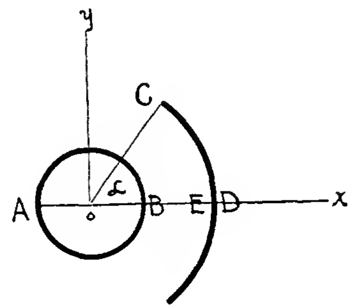

Fig 4

again, by considerations of symmetry, however the two conductors are charged, we need consider only the part of the plane above the x-axis. The same transformation (1) serves in this case. The w-plane is shown in fig. 5.

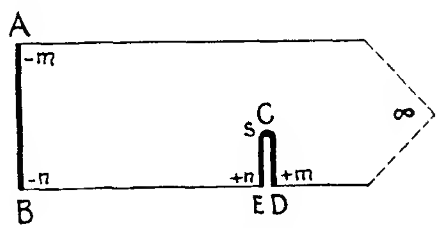

Fig. 5.

For this transformation we have

$$\frac{dw}{dt} = \frac{A(t - s)}{\{(t^2 - m^2)(t^2 - n^2)\}^{\frac{1}{2}}}.$$

The solution of this equation, of the same form as (7), is

$$w = iA \sin^{-1}\left\{\frac{m^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} + \frac{As}{m}\lambda + B, \tag{21}$$

where $t = n\, sn\, \lambda$, and the modulus is $k = n/m = 1/m^2$, if we again choose $nm = 1$. To determine the constants we shall take b as the radius of the cylinder and a that of the shell, and then we have,

$t = m$	n	$-n$	$-m$
$\lambda = K + iK'$	K	$-K$	$-K + iK'$
$w = \log a/c$	$\log a/c$	$\log b/c$	$\log b/c + i\pi$.

Since there is a jump in w of $i\pi$ at infinity, we find $A = 1$. We get, in addition,

$$\frac{s}{m} = \frac{\pi}{2K'}, \tag{22}$$

$$\log \frac{a}{b} = \frac{\pi K}{K'}, \tag{23}$$

and

$$B = \log \frac{a}{c} - \frac{\pi K}{2K'} - i\frac{\pi}{2}.$$

(23) determines the modulus of the elliptic functions from the ratio a/b.

On the circular arc t lies between m and n, and λ is $K + iv$, where v ranges from 0 at E to K' at D. $w = \log a/c + i\theta$ on this arc, and so we get

$$\theta = \sin^{-1} \frac{cn(v, k')}{dn(v, k')} - \frac{\pi}{2} + \frac{\pi v}{2K'}. \tag{24}$$

On the circular arc we must use that value of the inverse sine that is less than $\pi/2$.

At the edge C, $t = s$. Denote the corresponding value of v by v_0. Then we find from (22)

$$dn(v_0, k') = \frac{2K'k}{\pi}, \tag{25}$$

and, α being the angle of the shell,

$$\alpha = \sin^{-1} \frac{1}{k'} \left\{ 1 - \frac{\pi^2}{4K'^2} \right\}^{\frac{1}{2}} - \frac{\pi}{2} + \frac{\pi v_0}{2K'}. \tag{26}$$

It therefore follows that when the modular angle is determined by the ratio a/b the angle α of the shell is also determined. Our solution of the problem is not general enough to allow us to take arbitrary values of the ratio a/b and arbitrary values of α less than π. In order to generalize the solution, we may either give up the specification $t = \infty$ at the infinitely distant point of the z-plane, or, keeping this, we may discard the simplifying specification of $t = -m$ and $-n$ at the points A and B in fig. 4. The more general solution of this problem will be published later. It requires the use of the III Elliptic integral.

(26) shows that this particular solution of the problem gives a maximum value of $\pi/2$ for the angle α for the modular angle 0; in this limiting case $a = b$. For small modular angles, less than 1°, we can use approximations for the elliptic functions. For very small modular angles, we can put

$$dn(u, k') = \frac{\pi}{2K} \operatorname{sech} \frac{\pi u}{2K}.$$

Replacing the sech term by its approximate exponential value, gives

$$\frac{\pi v_0}{2K'} = \frac{90}{MK'} \log \frac{\pi}{K'k},$$

where the logarithm is to the base 10, M the base of the Naperian logarithms, and the result is expressed in degrees. K has been taken as $\pi/2$ for these small modular angles, and K' may be determined from the approximation

$$\log K' = \log \left(\log \frac{4}{k} \right) + \log \frac{1}{M}.$$

The following table gives the values of α and a/b for a few modular angles θ.

θ	α	a/b
1°	41° 12′	2.489
1′	56° 57′	1.678
1″	64° 32′	1.437
10^{-4} sec.	72° 46′	1.241
10^{-6} sec.	78° 8′	1.144

For larger values of the modular angle, equation (25) may be solved with the aid of the Smithsonian Tables. For example, with a modular angle of 5° it is found that $a/b = 3.645$ and $\alpha = 29^\circ\, 48'$.

For values of t lying between $-n$ and $+n$, we write

$$w = \sinh^{-1}\left\{\frac{n^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} + \frac{\pi(\lambda - K)}{2K'} + \log\frac{a}{c}. \qquad (27)$$

Along the x-axis from B to E, $\theta = 0$, and λ lies between $-K$ and $+K$. At $t = n$ this solution agrees with (21).

For values of t lying between $-m$ and $-n$, that is, on the cylinder of radius b,

$$w = i\sin^{-1}\left\{\frac{m^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} + \frac{\pi(\lambda - K)}{2K'} - i\frac{\pi}{2} + \log\frac{a}{c}. \qquad (28)$$

When $t = -n$, $\lambda = -K$, and this solution agrees with (27). We must now use that value of the inverse sine that is greater than $\pi/2$. The angle on this cylinder is given by

$$\theta = \frac{\pi}{2} - \sin^{-1}\left\{\frac{m^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} + \frac{\pi v}{2K'},$$

where $\lambda = -K + iv$ and $w = \log b/c + i\theta$. In this expression we use that value of the inverse sine that is less than $\pi/2$.

6. The χ-plane for the general case when the cylindrical shell is at potential V with a charge Q_1 per unit length, and the cylinder of radius b is at potential 0 with a charge Q_2 per unit length, is the same as in fig. 3, and the determination of the constants is the same as in Art. 2. The equations (9)–(14) are valid in this case. We shall get exactly the same results if we suppose that the cylinder of radius b is at the higher potential with a charge Q_1 and the shell at the lower potential with a charge Q_2. Combining (11) and (23) we find for the capacity of the condenser,

$$S = \frac{1}{4\log\frac{a}{b}}.$$

This is one-half the capacity of a condenser formed of two complete coaxial cylinders with the ratio of their radii a/b.

With the shell at potential V and with a charge Q_1, the complex potential is given by (14). When charged as a condenser, so that $Q_1 + Q_2 = 0$, we get on the shell, where $\lambda = K + iz$,

$$\psi = 2\pi Q \frac{z}{K'} + D'.$$

Since at the edge, $z = z_0$, we find for the charge on the convex side of the shell,

$$Q' = Q\left(1 - \frac{z_0}{K'}\right)$$

and on the concave side,

$$Q'' = Q\frac{z_0}{K'}.$$

If the two conductors are at the same potential so that $Q_1 = Q_2 = Q$, we find

$$\psi = -4Q\sin^{-1}\left\{\frac{m^2 - t^2}{m^2 - n^2}\right\}^{\frac{1}{2}} + D''.$$

The charge on the convex side of the shell is now

$$Q' = \frac{2Q}{\pi}\sin^{-1}\frac{cn(z_0, k')}{dn(z_0, k')},$$

and on the concave side,

$$Q'' = Q\left\{1 - \frac{2}{\pi}\sin^{-1}\frac{cn(z_0, k')}{dn(z_0, k')}\right\}.$$

The value of the inverse sine that is less than $\pi/2$ must be used in these expressions.

The surface density, σ, of the distribution on the shell is given by

$$\sigma = \frac{1}{2\pi a}\left\{(Q_1 + Q_2) + \frac{\pi(Q_1 - Q_2)}{2kK'}dn(z, k')\right\} \times \frac{dn(z_0, k')}{dn(z_0, k') - dn(z, k')}$$

v varies from 0 at E to K' at D. This is of course infinite at the edge where $v = v_0$. On the cylinder, where $\lambda = -K + iv$, the surface density is given by

$$\sigma = \frac{1}{2\pi b}\left\{ (Q_1 + Q_2) - \frac{\pi(Q_1 - Q_2)}{2kK'}\, dn(v, k') \right\} \times \frac{dn(v_0, k')}{dn(v_0, k') + dn(v, k')}.$$

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THE SPLIT CYLINDRICAL CONDENSER II

E. P. ADAMS

In this paper solutions are obtained for a number of problems connected with coaxial cylindrical conductors of infinite length. Some special cases of similar problems were considered in the preceding paper and the results there obtained will now be generalized.

Solutions are obtained for the distribution of electricity on the following systems:

(1) A cylindrical conductor partly surrounded by a coaxial cylindrical shell. Arts. 1–4.

(2) A cylindrical conductor partly surrounded by two equal coaxial cylindrical shells. Arts. 5–8.

(3) Two coaxial cylindrical shells when the line joining the middle points of the shells in any section perpendicular to the axis passes through the common centre of the two circles. Arts. 9–12.

(4) The same problem as (3) when the line joining the middle points of the two arcs lies wholly on one side of the common centre. Arts. 13–14.

1. We begin with the case of a cylindrical conductor of radius b, partly surrounded by a coaxial cylindrical shell of radius a. The angle subtended by this shell at the centre is 2α, where α is an angle lying between 0 and π. For $\alpha = \pi$ the shell becomes a complete cylinder. The transformation required in all the problems that we shall consider is

$$w = u + iv = \log z/c = \log r/c + i\theta, \tag{1}$$

r, θ being the polar coördinates of any point in the z-plane. In order to transform the w-plane to the t-plane we shall let the point at infinity in the z-plane correspond to $t = \infty$. Then if we take

$$-\infty < r < p < n < s < m < +\infty,$$

the transformation of the w- to the t-plane supplies the equation

$$\frac{dw}{dt} = \frac{A(t - s)}{(t - r\cdot t - p\cdot t - n\cdot t - m)^{\frac{1}{2}}}. \tag{2}$$

$t = s$ corresponds to the edge of the shell, and r, p, n, m in order correspond to the points where the x-axis meets the cylinder and the two faces of the shell as we go along the x-axis in the positive direction. There is a jump of $i\pi$ in w as we go from $t = +\infty$ to $t = -\infty$ around a semi-circle of infinite radius, and therefore $A = 1$. To solve (2) we shall use the substitution

$$t = \frac{p(n - r) - r(n - p)sn^2\lambda}{(n - r) - (n - p)sn^2\lambda}, \tag{3}$$

with the modulus, k, and the complementary modulus, k', given by

$$k^2 = \frac{(m - r)(n - p)}{(n - r)(m - p)}, \qquad k'^2 = \frac{(p - r)(m - n)}{(n - r)(m - p)}. \tag{4}$$

The solution of (2) is given by

$$w = -2\Pi(\lambda, \delta) + \frac{2(s - p)}{(m - p\cdot n - r)^{\frac{1}{2}}}\lambda + B, \tag{5}$$

where

$$\left.\begin{aligned} k^2 sn^2\delta &= \frac{n - p}{n - r}, & sn^2\delta &= \frac{m - p}{m - r}, \\ cn^2\delta &= \frac{p - r}{m - r}, & dn^2\delta &= \frac{p - r}{n - r} \end{aligned}\right\} \tag{6}$$

and

$$\Pi(\lambda, \delta) = sn\,\delta\,cn\,\delta\,dn\,\delta\int_0^\lambda \frac{k^2 sn^2\lambda d\lambda}{1 - k^2 sn^2\delta\, sn^2\lambda}. \tag{7}$$

For the determination of the constants, we have the scheme:

$t = m$	n	p	r
$\lambda = K + iK'$	K	0	iK'
$\Pi = (K + iK')Z(\delta) + \frac{i\pi\delta}{2K}$	$KZ(\delta)$	0	$iK'Z(\delta) + \frac{i\pi\delta}{2K} - i\frac{\pi}{2}$
$w = \log\frac{a}{c}$	$\log\frac{a}{c}$	$\log\frac{b}{c}$	$\log\frac{b}{c} + i\pi.$

Using these values in (5) we find,

$$\frac{s - p}{(m - p \cdot n - r)^{\frac{1}{2}}} = Z(\delta) + \frac{\pi\delta}{2KK'}. \tag{8}$$

$$B = \log\frac{b}{c}$$

and

$$\log\frac{a}{b} = \frac{\pi\delta}{K'}. \tag{9}$$

We can accordingly write

$$\log\frac{z}{b} = -2\Pi(\lambda, \delta) + 2\left\{Z(\delta) + \frac{\pi\delta}{2KK'}\right\}\lambda. \tag{10}$$

On the cylindrical shell, t lies between n and m, and

$$\lambda = K + iv,$$

where v lies between 0 and K'. Jacobi's Π function, defined by (7) expressed in terms of his Theta functions, is

$$\Pi(\lambda, \delta) = \frac{1}{2}\log\frac{\Theta(\lambda - \delta)}{\Theta(\lambda + \delta)} + \lambda Z(\delta). \tag{11}$$

With $\lambda = K + iv$, we get

$$\Pi(K + iv, \delta) = \frac{1}{2}\log\frac{\Theta_1(iv - \delta)}{\Theta_1(iv + \delta)} + (K + iv)Z(\delta). \tag{12}$$

Let us put

$$\log\frac{\Theta_1(iv - \delta)}{\Theta_1(iv + \delta)} = iF(v). \tag{13}$$

Then for $0 \leq v \leq K'$, $F(v)$ is real. On the shell,

$$w = \log\frac{a}{c} + i\theta$$

and so we get, from (9) and (10),

$$\theta = \frac{\pi v\delta}{KK'} - F(v). \tag{14}$$

This equation gives the relation between θ and v on the shell. Let v_0 be the value of v that corresponds to the edge of the

shell where $\theta = \alpha$. We can find v_0 by making θ, given by (14), a maximum. We therefore find

$$F'(v_0) = \frac{\pi\delta}{KK'}, \tag{15}$$

and the angle of the shell is given by

$$\alpha = \frac{\pi v_0 \delta}{KK'} - F(v_0). \tag{16}$$

The modular angle and δ are two independent quantities and we can therefore satisfy the conditions for any value of the ratio a/b greater than unity and for any value of the angle α between 0 and π. It would be difficult to solve these equations for assigned values of the ratio a/b and the angle α. But by assuming values for the modular angle and for δ we can find the corresponding values of a/b and α. It appears from (9) that small values of the modular angle correspond to values of the ratio a/b that are comparable with unity and it will be shown that values of δ nearly equal to K give values for α that are near to π.

The Theta functions are given by rapidly converging series in q or q', where

$$q = e^{-\frac{\pi K'}{K}}, \qquad q' = e^{-\frac{\pi K}{K'}}.$$

For very small modular angles, if we keep only terms in q, we find from (15)

$$\cosh 2v_0 = \frac{\pi\delta/K}{8K'q \sin \pi\delta/K}.$$

The term on the right is very large compared with unity if the modular angle is very small; we can therefore write

$$2v_0 = \frac{1}{M} \log \frac{\pi\delta/K}{4K'q \sin \pi\delta/K},$$

where $M = \log e$, and the logarithms are to the base 10.

From (13) we find with this approximation

$$F(z_0) = \tan^{-1}\frac{\pi\delta}{2KK'},$$

and from (16),

$$\alpha = \frac{\pi\delta}{2M}\frac{K}{K'}\log\frac{\pi\delta}{4K'q\sin\pi\delta/K}\frac{K}{} - \tan^{-1}\frac{\pi\delta}{2KK'}.$$

If $\delta = K/2$ we have the case considered in the previous paper. In order to compare the results of the present investigation with the previous one it must be remembered that we are now using a quadratic transformation and that accordingly our present q^2 corresponds to the q previously used. This is seen from the fact that in the present case, for $\delta = K/2$,

$$\log\frac{a}{b} = \frac{\pi K}{2K'} = \frac{\pi^2}{\log\frac{1}{q^2}},$$

while before we had

$$\log\frac{a}{b} = \frac{\pi K}{K'} = \frac{\pi^2}{\log\frac{1}{q}}.$$

2. We shall now transform the χ-plane to the t-plane for the general case when the cylinder has a charge Q_1 per unit length, at potential V, and the shell a charge Q_2 as potential 0. The differential equation is

$$\frac{d\chi}{dt} = \frac{C(t - s')}{(t - r\cdot t - p\cdot t - n\cdot t - m)^{\frac{1}{2}}}. \tag{17}$$

$t = s'$ corresponds to a point of equilibrium. There is a jump in χ of $-2\pi i(Q_1 + Q_2)$ in passing from $t = +\infty$ to $t = -\infty$, and so

$$C = -2(Q_1 + Q_2).$$

The solution of (17), which is of the same form as (2), is

$$\chi = -2C\Pi(\lambda, \delta) + 2C\frac{s' - p}{(m - p\cdot n - r)^{\frac{1}{2}}}\lambda + D.$$

The constants are to be determined from the values:

$$
\begin{array}{lllll}
t & = m & n & p & r, \\
\chi & = 2\pi i(Q_1 + Q_2) & 2\pi i Q_1 & V + 2\pi i Q_1 & V.
\end{array}
$$

We accordingly get

$$V = \frac{2\pi K}{K'}\left\{ Q_1 \frac{\delta}{K} - Q_2\left(1 - \frac{\delta}{K}\right)\right\}. \qquad (18)$$

This equation determines the difference of potential between the cylinder and the shell when the charges are given. We also find

$$\frac{s' - p}{(m - p \cdot n - r)^{\frac{1}{2}}} = \frac{\pi\delta}{2KK'} + Z(\delta) - \frac{\pi Q_2}{2K'(Q_1 + Q_2)}. \qquad (19)$$

This determines the point of equilibrium. We can now write

$$\chi = 4(Q_1 + Q_2)\left\{ \Pi(\lambda, \delta) - \left[\frac{\pi\delta}{2KK'} + Z(\delta)\right]\lambda + \frac{\pi\delta}{2K'}\right\} + \frac{2\pi Q_2}{K'}(\lambda - K) + 2\pi i Q_1. \qquad (20)$$

If the two conductors are at the same potential, $V = 0$, and (18) shows that the charges are in the ratio

$$\frac{Q_2}{Q_1} = \frac{\delta/K}{1 - \delta/K}. \qquad (21)$$

If the two conductors form a condenser so that $Q_1 + Q_2 = 0$, (18) gives for the capacity,

$$S = \frac{K'}{2\pi K}. \qquad (22)$$

By using (9) this may be written

$$S = \frac{\delta/K}{2\log\frac{a}{b}}. \qquad (23)$$

For $\delta = K/2$ the capacity is one-half that of a condenser consisting of two coaxial circular cylinders. This is the case that was considered in the previous paper.

On the shell,

$$\chi = i\psi, \qquad \lambda = K + iv,$$

and we can write

$$\psi = 2(Q_1 + Q_2)\left\{F(v) - \frac{\pi v\delta}{KK'}\right\} + \frac{2\pi Q_2 v}{K'} + 2\pi Q_1. \quad (24)$$

When the two conductors form a condenser so that $Q_1 + Q_2 = 0$, we find from (24) for the charge on the convex portion of the shell,

$$Q' = -Q\left(1 - \frac{v_0}{K'}\right),$$

where Q is the charge on the cylinder and $-Q$ that on the shell. This is very small when the shell is nearly a complete cylinder for then v_0 is nearly equal to K'.

If the two conductors are at the same potential, put $Q = Q_1 + Q_2$, the total charge on the system. Then from (24) and (21) we get on the shell,

$$\psi = 2Q\left\{F(v) + \pi\left(1 - \frac{\delta}{K}\right)\right\}.$$

Now,

$$F(K') = \frac{\pi\delta}{K}, \qquad F(0) = 0.$$

So the charge on the convex portion of the shell is

$$Q' = Q\left\{1 - \frac{v_0\delta}{KK'} + \frac{\alpha}{\pi}\right\}.$$

This is nearly the whole charge on the system if the shell is nearly a complete cylinder.

The electric intensity at any point is given by

$$R = -X + iY = \frac{d\chi}{dz} = \frac{1}{z}\frac{d\chi}{dt}\frac{dt}{dw} = \frac{C}{z}\frac{t - s'}{t - s}.$$

The edge of the shell corresponds to $t = s$, or $\lambda = K + iv_0$. We find from (3) and (8), making use of the relations (6),

$$dn^2(v_0, k') - k^2\, sn^2\,\delta = \frac{2KK'k^2\, sn\,\delta\, cn\,\delta\, dn\,\delta}{2KK'Z(\delta) + \pi\delta}.$$

If $Q_1 + Q_2 = 0$, $Q_2 = Q$, the case of the condenser, we find

$$R = -\frac{2\pi KQ}{z\{\pi\delta + 2KK'Z(\delta)\}}\frac{1 - k^2\, sn^2\,\delta\, sn^2\,\lambda}{1 - dn^2(v_0, k')sn^2\,\lambda}.$$

If the two conductors are at the same potential, we get, with $Q_1 + Q_2 = Q$,

$$R = -\frac{4QKK'}{z\, sn\,\delta\{2KK'Z(\delta) + \pi\delta\}} \times \frac{sn\,\delta Z(\delta) - \{cn\,\delta\, dn\,\delta + sn\,\delta\, Z(\delta)\}k^2\, sn^2\,\delta\, sn^2\,\lambda}{1 - dn^2(v_0, k')sn^2\,\lambda}.$$

From these expressions we can find the surface density, σ, at any point of the conductors. This is given by

$$R = 4\pi\sigma.$$

On the shell, $\lambda = K + iv$, $z = a$; and on the cylinder, $\lambda = iv$, $z = b$.

3. In a field along the x-axis there will be in general two points of equilibrium. The values of t corresponding to these will be taken as s' and s'', where $s' > s''$. If the two conductors are insulated and uncharged we shall have $n < s' < m$, and $r < s'' < p$; while if the two conductors are at the same potential we shall have $n > s' > s'' > p$. The differential equation for transforming from the χ- to the t-plane for both cases is

$$\frac{d\chi}{dt} = \frac{C(t - s')(t - s'')}{(t - r\cdot t - p\cdot t - n\cdot t - m)^{\frac{1}{2}}}. \tag{25}$$

It will be found advantageous to take $r = 0$; this can be done without loss of generality. Then the substitution (3) leads to

$$\begin{aligned}\frac{\chi}{C'} = {} & \frac{sn\,\delta}{cn\,\delta\, dn\,\delta}\left\{\frac{2(s' + s'')}{p} - \frac{cn^2\,\delta + dn^2\,\delta + cn^2\,\delta\, dn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}\right\}\Pi(\lambda, \delta) \\ & + \frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}\left\{Z(\lambda) - \frac{k^2\, sn^2\,\delta\, sn\,\lambda\, cn\,\lambda\, dn\,\lambda}{1 - k^2\, sn^2\,\delta\, sn^2\,\lambda}\right\} \\ & + \left\{\frac{E}{K}\frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta} + \frac{1 + cn^2\,\delta}{cn^2\,\delta} + \frac{2(s' + s'')}{p} - \frac{2s's''}{p^2}\right\}\lambda + D.\end{aligned}$$

The constant C' has been written for $p^2C/(n\cdot m - p)^{\frac{1}{2}}$.

We shall first suppose that the two conductors are uncharged, with a difference of potential V between them. Then $\chi = V$ for $\lambda = K + iK'$ and for $\lambda = K$; while $\chi = 0$ for $\lambda = 0$ and for $\lambda = iK'$. It will be found that the points of equilibrium are given by

$$\frac{2(s' + s'')}{p} = \frac{cn^2\,\delta + dn^2\,\delta + cn^2\,\delta\, dn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta} \tag{26}$$

and

$$\frac{2s's''}{p^2} = \frac{1}{cn^2\,\delta\, dn^2\,\delta}\left(1 - \frac{E'}{K'} sn^2\,\delta\right). \tag{27}$$

The difference of potential between the two conductors is given by

$$\frac{V}{C'} = \frac{\pi}{2K'} \frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}. \tag{28}$$

We can now write

$$\frac{\chi}{C'} = \frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}\left\{ Z(\lambda) - \frac{k^2\, sn^2\,\delta\; sn\,\lambda\; cn\,\lambda\; dn\,\lambda}{1 - k^2\, sn^2\,\delta\; sn^2\,\lambda} \right\} + \frac{\pi}{2KK'} \frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}\lambda. \tag{29}$$

The constant C' must be determined so that the potential at infinity shall be $\varphi = Fx$, where F is the electric intensity. At infinity, $t = \infty$, and by (3) and (6) when $t = \infty$,

$$sn^2\,\lambda = \frac{n}{n - p} = \frac{1}{k^2\, sn^2\,\delta},$$

with $r = 0$. It therefore follows that the value of λ corresponding to $z = \infty$ is

$$\lambda = \delta + iK'.$$

Put

$$\lambda = iK' + \delta + \epsilon, \tag{30}$$

and we find from (29) when ϵ approaches zero,

$$\frac{\chi}{C'} = \frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}\frac{1}{2\epsilon}.$$

From (10) and (11) we have

$$\log\frac{z}{b} = \frac{\pi\delta}{KK'}\lambda - \log\frac{\Theta(\lambda - \delta)}{\Theta(\lambda + \delta)}.$$

If we use the value (30) for λ we find, when ϵ approaches zero,

$$\frac{z}{b} = \frac{H(2\delta)e^{\frac{\pi\delta^2}{KK'}}}{\epsilon H'(0)}.$$

In this, H is Jacobi's Eta function, and

$$H'(0) = \left(\frac{2kk'K}{\pi}\right)^{\frac{1}{2}}. \tag{32}$$

For a real value of ϵ, $z = x$, and as ϵ approaches zero we find

$$x = \frac{bH(2\delta)e^{\frac{\pi\delta^2}{KK'}}}{\epsilon H'(0)}.$$

In order, therefore, that the potential be Fx when x is infinite, we must have

$$C' = \frac{2bF\,cn^2\,\delta\,dn^2\,\delta}{sn^2\,\delta}\,\frac{H(2\delta)e^{\frac{\pi\delta^2}{KK'}}}{H'(0)}. \tag{33}$$

We can now write for the difference of potential between the two conductors,

$$V = \frac{bF}{K'}\,\frac{H(2\delta)}{H'(0)}\,e^{\frac{\pi\delta^2}{KK'}}.$$

Let $\delta = K - \epsilon$, where ϵ is small so that the shell is nearly a complete cylinder. We have, in this case,

$$H(2\delta) = 2\epsilon H'(0)$$

and the difference of potential between the two conductors is, using (9),

$$V = \frac{2Fa\pi}{K'}\epsilon.$$

This vanishes, as it should, with ϵ.

If the shell and the cylinder are at the same potential, the induced charges on the conductors will be equal and opposite in sign. Let these charges be $\pm Q$. Then we must have $\chi = 2\pi i Q$ for $t = n$ and p, and $\chi = 0$ for $t = m$ and r. Then we get equation (26) as before while instead of (27) we have

$$\frac{2s's''}{p^2} = \frac{1}{cn^2\,\delta\, dn^2\,\delta}\left(cn^2\,\delta + \frac{E}{K}sn^2\,\delta\right).$$

Q is given by

$$\frac{2\pi Q}{C'} = \frac{\pi}{2K}\frac{sn^2\,\delta}{cn^2\,\delta\, dn^2\,\delta}.$$

The value of C' is given by (33).

If $\delta = K - \epsilon$, with ϵ small, so that the shell is nearly a complete cylinder, this becomes

$$Q = \frac{Fa\epsilon}{K}, \tag{34}$$

and it vanishes with ϵ.

4. In a field along the y-axis the χ-plane for the induced charges is simply the t-plane turned through a right angle. So we can write

$$\chi = iCt.$$

The constant C must be determined so that the potential at infinity shall be Fy. Proceeding as in the previous case, we find

$$C = -\frac{2bFH(2\delta)cn\,\delta\, dn\,\delta e^{\frac{\pi\delta^2}{KK'}}}{H'(0)sn^2\,\delta}.$$

We therefore have

$$\chi = \frac{iC}{1 - k^2\, sn^2\,\delta\, sn^2\,\lambda}.$$

From this expression the induced charges on the upper halves of the shell and the cylinder may be obtained. For the former we find

$$Q' = \frac{Ck'^2\, sn^2\,\delta}{4\pi\, cn^2\,\delta\, dn^2\,\delta},$$

and for the induced charge on the upper half of the cylinder,

$$Q'' = \frac{C}{4\pi}.$$

If $\delta = K - \epsilon$, with ϵ small so that the shell is nearly a complete cylinder, we find

$$Q' = \frac{aF}{\pi},$$

if ϵ^2 be neglected. This is the same as if the shell were a complete cylinder and follows from elementary theory. Similarly, for the induced charge on the cylinder, we get

$$Q'' = \frac{aFk'^2\epsilon^2}{\pi}.$$

Comparing this expression with (34) shows that the shielding is more effective for a field along the y- than along the x-axis.

5. We can use the same method, and many of the results that have been obtained, to get the solution of the second problem. Let there be a cylinder of radius b and outside of it two equal cylindrical shells of radius a, each of them subtending an angle 2α at the centre. The angle α may have any value between 0 and $\pi/2$. If we take the x-axis along the line that bisects both the circular arcs it will be sufficient, on account of the symmetry, to consider only the positive quadrant of the z-plane, enclosed within the dotted lines in fig. 1. This involves a limitation in the electrical state that can be assumed. The x-axis will be a line of force in any case; the y-axis must be either an equipotential or a line of force. If it is an equipotential, the charges on the two shells will be equal and opposite, and the potential of the cylinder, as well as the potential along the y-axis, will be midway between that of the two shells. If the y-axis, external to the cylinder, is a line of force the charges on the two shells will be equal and of the same sign: the potential of the cylinder may differ from that of the shells.

We can use all of our previous results for the transformation of the w- to the t-plane. But since the jump in w as t passes from $+\infty$ to $-\infty$ is now $i\pi/2$, instead of $i\pi$, the

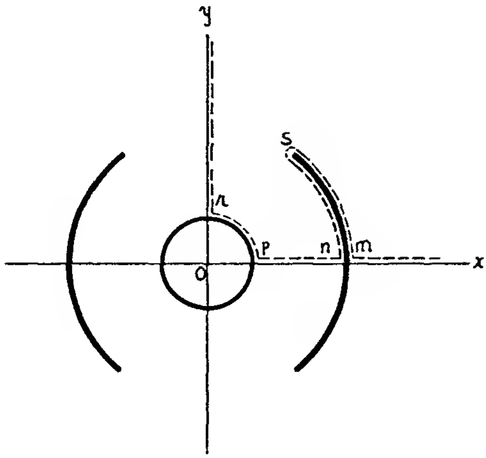

Fig 1

expression (10) for w must be divided by 2. Equation (15) for determining v_0 is valid in this case, while the right hand members of (9), (10), (14) and (16) must be divided by 2.

We shall first suppose that the cylinder is at potential V, with a charge Q per unit length, while each shell is at potential 0 with a charge $-Q/2$ per unit length. Then the differential equation for the transformation of the χ- to the t-plane is

$$\frac{d\chi}{dt} = \frac{C}{(t - r \cdot t - p \cdot t - n \cdot t - m)^{\frac{1}{2}}}. \qquad (35)$$

Its solution is

$$\chi = -\frac{2C}{(m - p \cdot n - r)^{\frac{1}{2}}}\lambda + D,$$

where λ is given by (3). The constants are to be determined from the values:

$t = m$	n	p	r
$\lambda = K + iK'$	K	0	iK'
$\chi = 0$	$i\pi Q$	$V + i\pi Q$	$V.$

We find

$$\frac{2C}{(m-p\cdot n-r)^{\frac{1}{2}}}=\frac{\pi Q}{K'},$$

and

$$V=\frac{\pi K Q}{K'}.$$

Therefore the capacity of the condenser per unit length is

$$S=\frac{K'}{\pi K},$$

or, using (9), (divided by 2),

$$S=\frac{\delta}{2K\log\frac{a}{b}}.$$

If $\delta = K$, the two shells form a complete cylinder and we get the expression for the capacity of a condenser consisting of two coaxial cylinders.

The electric intensity at any point in this case is found to be,

$$\frac{d\chi}{dz}=-\frac{2\pi Q K}{2KK'Z(\delta)+\pi\delta}\,\frac{1-k^2\,sn^2\,\delta\,sn^2\,\lambda}{1-dn^2(v_0,k')sn^2\,\lambda}\cdot\frac{1}{z}.$$

From this the surface density may be found at any point of the conductors. On the shell, $\lambda = K + iv$, and on the cylinder, $\lambda = iv$, where v varies from 0 to K'.

6. Now let us suppose that the shell on the right is at potential V with a charge Q, the other shell being at potential $-V$ with a charge $-Q$ per unit length. The cylinder, and also the y-axis external to it, is at potential 0. The two halves of the cylinder, divided by the y-axis, will have charges $\pm Q_1$. The differential equation for transforming from the χ- to the t-plane is now

$$\frac{d\chi}{dt}=\frac{C}{(t-p\cdot t-n\cdot t-m)^{\frac{1}{2}}}. \qquad (36)$$

We shall integrate this equation by putting

$$t = n\, sn^2(\lambda, l) + p\, cn^2(\lambda, l) \tag{37}$$

with the modulus, l, given by

$$l^2 = \frac{n-p}{m-p}.$$

The solution is

$$\chi = -\frac{2C}{(m-p)^{\frac{1}{2}}}\lambda + D.$$

The constants are to be determined from the conditions,

$$\begin{array}{lll} t = m & n & p \\ \lambda = K(l) + iK'(l) & K(l) & 0 \\ \chi = V + i\pi Q & V & 0. \end{array}$$

We find

$$\frac{2C}{(m-p)^{\frac{1}{2}}} = -\frac{V}{K(l)},$$

and

$$\pi Q = \frac{VK'(l)}{K(l)}.$$

$K(l)$ and $K'(l)$ are the complete elliptic integrals of the first kind to the modulus l and the complementary modulus l'. The relation between the modulus l and the modulus k is given by

$$l = k\frac{cn\,\delta}{dn\,\delta}. \tag{38}$$

The difference of potential between the two shells is $2V$, and so the capacity of the condenser is given by

$$S = \frac{K'(l)}{2\pi K(l)}.$$

The electric intensity is now given by

$$\frac{d\chi}{dz} = \frac{2VKK'\,dn\,\delta}{K(l)\{2KK'Z(\delta) + \pi\delta\}}\,\frac{\{1 - k^2\,sn^2\,\delta\,sn^2(\lambda, l)\}^{\frac{1}{2}}}{1 - dn^2(v_0, k')sn^2(\lambda, l)}\cdot\frac{1}{z}.$$

From this expression the surface density at any point of the conductors can readily be found.

7. Let us now suppose that the system consisting of the two shells and the cylinder is placed in an electric field along the x-axis. We first suppose that both the shells and the cylinder are uncharged and that there is a difference of potential $2V$ between the two shells. We shall take $\varphi = 0$ as the potential of the cylinder and $\varphi = +V$ as the potential of the shell on the right. The y-axis, as well as the cylinder, is now the equipotential $\varphi = 0$. We consider again only the positive quadrant of the z-plane, and the differential equation for transforming from the χ- to the t-plane is

$$\frac{d\chi}{dt} = \frac{C(t - s')}{(t - p\cdot t - n\cdot t - m)^{\frac{1}{2}}}. \tag{39}$$

$t = s'$ corresponds to the point on the shell where the surface density changes in sign; the whole charge on the shell vanishes. We shall solve this equation by using the substitution (37), and we get

$$\chi = 2C(m - p)^{\frac{1}{2}}\left\{ Z(\lambda, l) - \left[1 - \frac{E(l)}{K(l)} \right]\lambda + \frac{s' - p}{m - p}\lambda \right\} + D.$$

$\chi = V$ for $t = m$ and for $t = n$; $\chi = 0$ for $t = p$. Accordingly we find

$$\frac{2(s' - p)}{m - p} = \frac{\pi}{K(l)K'(l)} + 2\left\{ 1 - \frac{E(l)}{K(l)} \right\},$$

and

$$V = C(m - p)^{\frac{1}{2}}\frac{\pi}{K'(l)}.$$

We therefore get

$$\chi = C'\left\{ Z(\lambda, l) + \frac{\pi\lambda}{2K(l)K'(l)} \right\}.$$

The constant C' has been written for $2C(m - p)^{\frac{1}{2}}$. It must be determined so that the potential at infinity shall be $\varphi = Fx$. When $z = \infty$, $t = \infty$, and $\lambda = iK'(l)$. Let us put $\lambda = iK'(l) + \epsilon'$. Then as ϵ' approaches zero we find that χ approaches

the value

$$\text{Limit } \chi = \frac{C'}{\epsilon'} = Fx.$$

On account of the factor 2, we get in the present problem, instead of (31),

$$\frac{z^2}{b^2} = \frac{H(2\delta)e^{\frac{\pi\delta^2}{KK'}}}{H'(0)}.$$

Now the points of the z-plane corresponding to $\lambda = iK'(l) + \epsilon'$ and to $\lambda = iK'(k) + \delta + \epsilon$ must be the same; therefore the corresponding values of t must be the same. So we find from (3) and (52)

$$\frac{1}{\epsilon} = \frac{2}{\epsilon'^2}\frac{k^2}{l^2}\frac{sn\ \delta\ cn\ \delta}{dn\ \delta}.$$

From this it follows that the value of the constant C' is given by

$$C' = \frac{Fbk}{l}\left\{\frac{2H(2\delta)e^{\frac{\pi\delta^2}{KK'}}}{H'(0)}\frac{sn\ \delta\ cn\ \delta}{dn\ \delta}\right\}^{\frac{1}{2}}. \tag{40}$$

We next assume that both the shells and the cylinder are at the same potential in the field F along the x-axis. Then the two shells will have equal and opposite charges, $\pm Q$, and the induced charge on the cylinder will vanish, or the induced charges on the two halves of it will be $\pm Q_1$. We have the same differential equation for transforming from the χ- to the t-plane, but subject now to the conditions

$$\begin{array}{llll} t = & m & n & p, \\ \chi = & -2\pi i(Q + Q_1) & -2\pi i Q_1 & -2\pi i Q_1. \end{array}$$

We find

$$\frac{s' - p}{m - p} = 1 - \frac{E(l)}{K(l)}.$$

This equation determines the point of equilibrium upon the shell to the right. In addition, we get

$$2\pi Q = \frac{C'\pi}{2K(l)}$$

for the induced charges, $\pm Q$. The value of the constant is again given by (40), and we find that when $\delta = K$, so that the two shells form a complete cylinder, we get the known result $Q = Fa\,\pi$.

In order to find Q_1, we must determine the value of ψ for $t = r$. The solution of (39) is now

$$\chi = C'Z(\lambda, l) - 2\pi i Q_1.$$

For $t = r$, λ lies between 0 and $iK'(l)$. So we take $\lambda = iv_1$, where

$$sn(v_1, l') = dn\,\delta, \quad \text{or} \quad dn(v_1, l') = k.$$

v_1 is thus determined and the value of Q_1 can then be deduced from the expression for χ.

8. In a field along the y-axis, the χ-plane is the positive quadrant of the t-plane turned through a right angle. It therefore follows that

$$\chi = iCt^{\frac{1}{2}},$$

and the constant C is to be determined so as to make the potential at infinity equal to $\varphi = Fy$. We find, in the same way as before,

$$p^{\frac{1}{2}}C = Fb\left\{\frac{2\,cn\,\delta\,dn\,\delta}{sn\,\delta}\frac{H(2\delta)}{H'(0)}e^{\frac{\pi\delta^2}{KK'}}\right\}^{\frac{1}{2}},$$

and the complex potential is given by

$$\chi = \frac{ip^{\frac{1}{2}}C}{(1 - k^2\,sn^2\,\delta\,sn^2\,\lambda)^{\frac{1}{2}}}.$$

If $\delta = K - \epsilon$, where ϵ is small, so that the two shells form nearly a complete cylinder, we find, for the charge induced on the upper half of each shell,

$$Q = \frac{Fa}{\pi}(1 - \epsilon)$$

and, for the charge induced on the upper half of the cylinder

$$Q_1 = \frac{Fa}{\pi}k'\epsilon.$$

9. The third problem is a generalization of the first problem of the earlier paper. Here there are two cylindrical shells (Fig. 2) of radii a and b. 2α and 2β are the angles

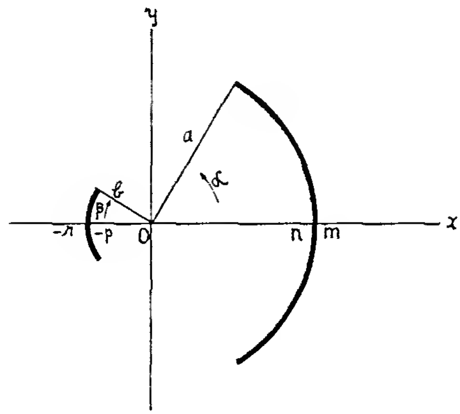

Fig 2

subtended by the circular arcs at the origin. We shall take $t = \infty$ to correspond to the point at infinity and $t = 0$ to correspond to the origin, $z = 0$. We now choose r, p, n, m so that

$$-\infty < -r < -s_2 < -p < 0 < n < s_1 < m < +\infty.$$

As we proceed along the x-axis in the positive direction from $-\infty$, $t = -r$ and $t = -p$ correspond to the two faces of the shell of radius b, and $t = -s_2$ to the edge of this shell. Similarly, $t = n$ and $t = m$ correspond to the points where the x-axis meets the two faces of the shell of radius a, and $t = s_1$ to the edge of this shell. The differential equation for the transformation from the z- to the t-plane is now

$$\frac{dz}{dt} = \frac{A}{t} \frac{(t + s_2)(t - s_1)}{(t + p \cdot t + r \cdot t - n \cdot t - m)^{\frac{1}{2}}}. \tag{41}$$

As we pass from $t = +\infty$ to $t = -\infty$ along a semi-circle of infinite radius there is a jump of $i\pi$ in z. Hence $A = 1$. There is a jump of $-i\pi$ in z as we pass through the origin where $t = 0$. So we find

$$A = \frac{(rpnm)^{\frac{1}{2}}}{s_1 s_2} = 1. \tag{42}$$

To integrate (41) we shall use the substitution obtained from (3) by changing the signs of r and p. Then the integral of (41) may be written

$$w = -2\Pi(\lambda, \delta) - 2\Pi_1(\lambda, \gamma) + J\lambda + B.$$

Jacobi's Π function is given by (7) and (11) and we now have

$$\left.\begin{aligned} k^2\, sn^2\,\delta &= \frac{n+p}{n+r} \qquad & cn^2\,\delta &= \frac{r-p}{m+r} \\ sn^2\,\delta &= \frac{m+p}{m+r} \qquad & dn^2\,\delta &= \frac{r-p}{n+r} \end{aligned}\right\}. \tag{43}$$

We also have

$$\begin{aligned} \Pi_1(\lambda, \gamma) &= sn\,\gamma\; cn\,\gamma\; dn\,\gamma \int_0^\lambda \frac{d\lambda}{sn^2\,\gamma - sn^2\,\lambda} \\ &= -\frac{1}{2}\log\frac{H(\gamma-\lambda)}{H(\gamma+\lambda)} - \lambda Z(\gamma), \end{aligned} \tag{44}$$

and γ is defined by

$$sn^2\,\gamma = \frac{p(n+r)}{r(n+p)},\; cn^2\,\gamma = \frac{n(r-p)}{r(n+p)},\; dn^2\,\gamma = \frac{m(r-p)}{r(m+p)}. \tag{45}$$

These definitions make both δ and γ real. The point at infinity is given by $\lambda = iK' + \delta$, and the origin by $\lambda = \gamma$. J is used as an abbreviation for

$$J = \frac{2r}{(n+r\cdot m+p)^{\frac{1}{2}}}\left\{\frac{p}{r} - \frac{s_2 - s_1}{r} - \frac{s_1 s_2}{r^2}\right\}. \tag{46}$$

For the determination of the constants we have the values

$t =$	m	n	$-p$	$-r$
$\lambda =$	$K + iK'$	K	0	iK'
$w =$	$\log\frac{a}{c}$	$\log\frac{a}{c}$	$\log\frac{b}{c} + i\pi$	$\log\frac{b}{c} + i\pi.$

The values of $\Pi(\lambda, \delta)$ for these four arguments have already

been given in Art. 1; for $\Pi_1(\lambda, \gamma)$ we have

$$\Pi_1(K + iK', \gamma) = -(K + iK')Z(\gamma) - \frac{i\pi\gamma}{2K} + i\frac{\pi}{2},$$

$$\Pi_1(K, \gamma) = -KZ(\gamma) + i\frac{\pi}{2},$$

$$\Pi_1(0, \gamma) = 0,$$

$$\Pi_1(iK', \gamma) = -iK'Z(\gamma) - \frac{i\pi\gamma}{2K} + i\frac{\pi}{2}.$$

Substitution of these values leads to

$$J = 2Z(\delta) - 2Z(\gamma) + \frac{\pi}{KK'}(\delta - \gamma),$$

and

$$\log\frac{a}{b} = \frac{\pi}{K'}(\delta - \gamma). \tag{47}$$

If $\delta = \gamma$, we have $a = b$, and the two shells form parts of the same cylinder. This is the case that we shall now consider. From (42) we get, using the relations (43) and (45),

$$\frac{s_1 s_2}{r^2} = \left(\frac{p}{r}\cdot\frac{n}{r}\cdot\frac{m}{r}\right)^{\frac{1}{2}} = k^2\, sn^4\, \delta.$$

We find also

$$\frac{p}{r} = k^2\, sn^4\, \delta.$$

Since $J = 0$ if $\delta = \gamma$, (46) shows that

$$\frac{s_1}{r} = \frac{s_2}{r} = k\, sn^2\, \delta,$$

$t = s_1$ corresponds to the edge of the right-hand shell, and for this point we shall take $\lambda = K + iv_1$. From (3), after changing the signs of r and p, we find

$$v_1 = \tfrac{1}{2}K'.$$

The value of λ at the edge of the shell of angle α is therefore $\lambda = K + iK'/2$. For the edge of the shell of angle β we find $\lambda = iK'/2$.

We can now write the solution of (41)

$$\log \frac{z}{a} = -2\Pi(\lambda, \delta) - 2\Pi_1(\lambda, \gamma) + i\pi,$$

or, in terms of the Theta functions,

$$\frac{z}{a} = \frac{\Theta(\lambda + \delta)}{H(\lambda + \delta)} \frac{H(\lambda - \delta)}{\Theta(\lambda - \delta)}.$$

But since

$$\sqrt{k}\, sn\, u = \frac{H(u)}{\Theta(u)},$$

we get

$$\frac{z}{a} = \frac{sn(\lambda - \delta)}{sn(\lambda + \delta)}. \tag{48}$$

For a point on the shell of angle α we take $\lambda = K + iv$. Let θ be the angle corresponding to v. Then we get from (48)

$$\tan \theta = \frac{2k'^2\, sn(v, k')cn(v, k')dn(v, k')sn\, \delta\, cn\, \delta\, dn\, \delta}{dn^2(v, k')cn^2\, \delta\, dn^2\, \delta - k'^4\, sn^2(v, k')cn^2(v, k')sn^2\, \delta}. \tag{49}$$

The value of θ is the same for $K' - v$ as v. Values of v less than $K'/2$ correspond to the concave side of the shell, and values greater than $K'/2$ correspond to the convex side of the shell. The angle θ' measured from the positive x-axis to a point on the shell to the left is given by putting $\lambda = iv$ in (48) and we get

$$\tan \theta' = \frac{2\, sn(v, k')cn(v, k')dn(v, k')sn\, \delta\, cn\, \delta\, dn\, \delta}{sn^2(v, k')cn^2(v, k')cn^2\, \delta\, dn^2\, \delta - dn^2(v, k')sn^2\, \delta}. \tag{50}$$

Values of v less than $K'/2$ correspond to the concave side of the shell, and greater values to the convex side.

If we put $v = K'/2$ in (49) and (50) we get expressions for the angles α and β. In this way we find

$$\tan \alpha = \frac{2(1 - k)sn\, \delta\, cn\, \delta\, dn\, \delta}{cn^2\, \delta\, dn^2\, \delta - (1 - k)^2 sn^2\, \delta}. \tag{51}$$

$$\tan (\pi - \beta) = \frac{2(1 + k)sn\, \delta\, cn\, \delta\, dn\, \delta}{cn^2\, \delta\, dn^2\, \delta - (1 + k)^2 sn^2\, \delta}. \tag{52}$$

With $\delta = K/2$ we have the special case considered in the earlier paper. For this case we derive

$$\tan\alpha = \tan\beta = \frac{k'}{k}$$

or

$$\sin\alpha = k' = \cos\theta,$$

if θ now denotes the modular angle. We found before

$$\sin\alpha = \frac{1-l}{1+l},$$

if we denote by l the modulus previously used. The relation between the modulus k and the modulus l expressed by

$$k' = \frac{1-l}{1+l}$$

is just the relation to be expected when q is replaced by q^2.

We now have two independent variables, the modular angle, or k, and δ. So we can give α and β any values less than $\pi/2$ independently of each other. It is necessary to consider only values of δ less than $K/2$, for (51) and (52) show that α and β are interchanged when K is replaced by $K - \delta$.

As an illustration, for the modular angle 15° we get the following results for $\delta = K/6$, $K/3$, and $K/2$:

δ	α	β
$K/6$	22° 54′	142° 2′
$K/3$	47° 25′	106° 34′
$K/2$	75°	75°

For the modular angle 45° we find:

δ	α	β
$K/6$	10° 50′	122° 0′
$K/3$	39° 54′	70° 10′
$K/2$	45°	45°

The smaller the modular angle, the smaller is the angular width of the slit between the two cylindrical shells. The angles α and β approach equality as δ nears $K/2$.

In the more general case when the ratio a/b differs from unity, we have three independent variables: the modular angle, δ and γ. So it is possible to give arbitrary values to the ratio a/b, α, and β independently of each other. The analysis required for this case is similar to that required for the fourth problem.

10. We shall now suppose that the shell to the left has a charge Q_2 per unit length, at potential 0, while the shell to the right has a charge Q_1 at potential V. Then the differential equation for the transformation from the χ- to the t-plane is

$$\frac{d\chi}{dt} = \frac{C(t+s)}{(t+r\cdot t+p\cdot t-n\cdot t-m)^{\frac{1}{2}}}; \tag{53}$$

$t = -s$ corresponds to a point of equilibrium. There is a jump in χ of $-2\pi i(Q_1+Q_2)$ when t passes from $+\infty$ to $-\infty$, so that

$$C = -2(Q_1+Q_2).$$

The integral of (53) may be written

$$\frac{\chi}{C} = -2\Pi(\lambda, \delta) + \frac{2\,cn\,\delta\,dn\,\delta\left(k^2\,sn^2\,\delta\,sn^2\,\gamma - \frac{s}{r}\right)}{sn\,\delta(1-k^2\,sn^2\,\delta\,sn^2\,\gamma)}\lambda + D.$$

The conditions to be satisfied are:

$$\begin{array}{lllll} t = & m & n & -p & -r, \\ \chi = & V + 2\pi i(Q_1+Q_2) & V + 2\pi i Q_2 & 2\pi i Q_2 & 0. \end{array}$$

We find, on substitution,

$$\chi = 4(Q_1+Q_2)\left\{\Pi(\lambda,\delta) - \left[Z(\delta) + \frac{\pi\delta}{2KK'}\right]\lambda\right\} + \frac{2\pi Q_1}{K'}\lambda + 2\pi i Q_2, \tag{54}$$

$$V = 2\pi Q_1\frac{K}{K'} - 2\pi\frac{\delta}{K'}(Q_1+Q_2). \tag{55}$$

If $Q_1 + Q_2 = 0$, so that the two shells form a condenser, we have, with $Q_1 = Q = -Q_2$,

$$V = \frac{2\pi Q K}{K'}.$$

Therefore the capacity of the condenser is

$$S = \frac{K'}{2\pi K},$$

and depends only upon the modular angle. By using (47) We may write

$$S = \frac{\delta - \gamma}{2K \log \dfrac{a}{b}}.$$

If $\delta = \gamma$, so that the shells are parts of the same cylinder it may be shown that the charges are equally divided between their convex and concave sides.

When the two shells, forming parts of the same cylinder, have equal and opposite charges, the electric intensity is given by

$$\frac{d\chi}{dz} = -\frac{\pi Q}{zK'} \frac{k^2\, sn^2\,\delta\, cn^2\,\delta + dn^2\,\delta}{sn\,\delta\, cn\,\delta\, dn\,\delta} \times \frac{(sn^2\,\lambda - sn^2\,\delta)(1 - k^2\, sn^2\,\delta\, sn^2\,\lambda)}{(1 + k^2\, sn^4\,\delta)(1 - k^2\, sn^4\,\lambda)}. \tag{56}$$

This becomes infinite at the edges where $sn^4\,\lambda = 1/k^2$; it vanishes only at infinity where $sn\,\lambda = 1/(k\, sn\,\delta)$. At the origin, where $z = 0$, $\lambda = \delta$. But we find from (48) that in the limit

$$\frac{sn^2\,\lambda - sn^2\,\delta}{z} = \frac{2}{a} sn\, 2\delta\, cn\,\delta\, dn\,\delta.$$

From the expression for the electric intensity the surface density on the conductors may easily be determined.

If the two shells are at the same potential, we find from (55) that their charges are in the ratio

$$\frac{Q_1}{Q_2} = \frac{\delta/K}{1 - \delta/K}, \tag{57}$$

and this is independent of γ.

11. When the system of the two cylindrical shells is placed in an electric field along the x-axis, the differential equation

for the transformation from the χ- to the t-plane is

$$\frac{d\chi}{dt} = \frac{C(t + s'')(t - s')}{(t + r \cdot t + p \cdot t - n \cdot t - m)^{\frac{1}{2}}}.$$

This is similar to equation (25), but we cannot now take advantage of the simplification arising from taking $r = 0$. Its solution may be expressed in the form,

$$\frac{\chi}{rC} = T\Pi(\lambda, \delta) + S\lambda + (1 - k^2 sn^2\,\delta\, sn^2\,\gamma)\frac{sn\,\delta}{cn\,\delta\, dn\,\delta} \times \left\{ Z(\lambda) - \frac{k^2 sn^2\,\delta\, sn\,\lambda\, cn\,\lambda\, dn\,\lambda}{1 - k^2 sn^2\,\delta\, sn^2\,\lambda} \right\} + D.$$

T and S are used as abbreviations for

$$T = \left\{ 4 - \frac{(1 - k^2 sn^2\,\delta\, sn^2\,\gamma)(cn^2\,\delta + dn^2\,\delta + cn^2\,\delta\, dn^2\,\delta)}{cn^2\,\delta\, dn^2\,\delta} \right\} \times \frac{sn\,\delta}{cn\,\delta\, dn\,\delta} - \frac{2(s'' - s')}{r}.$$

$$S = \frac{2\,cn\,\delta\, dn\,\delta}{sn\,\delta}\,\frac{1 - 2k^2 sn^2\,\delta\, sn^2\,\gamma}{1 - k^2 sn^2\,\delta\, sn^2\,\gamma} - \frac{cn^2\,\delta + dn^2\,\delta - cn^2\,\delta\, dn^2\,\delta}{sn\,\delta\, cn\,\delta\, dn\,\delta} - \frac{sn\,\delta}{cn\,\delta\, dn\,\delta}\left(1 - \frac{E}{K}\right)(1 - k^2 sn^2\,\delta\, sn^2\,\gamma) + \frac{2\,cn\,\delta\, dn\,\delta}{sn\,\delta(1 - k^2 sn^2\,\delta\, sn^2\,\gamma)}\,\frac{s's''}{r^2}.$$

We shall suppose that the two shells are at the same potential; then the conditions to be satisfied are,

$$\begin{array}{lllll} t = & m & n & -p & -r, \\ \chi = & 0 & 2\pi i Q & 2\pi i Q & 0. \end{array}$$

$-Q$ is the charge induced on unit length of the shell to the right of the origin, and $+Q$ the charge induced on the shell to the left when the field is along the negative x-axis. When these conditions are used, we find

$$T = S = 0.$$

and thus the points of equilibrium, s' and s'', are determined. We find also

$$D = \frac{2\pi i Q}{C'},$$

and therefore we can write

$$\frac{\chi}{C'} = (1 - k^2\, sn^2\,\delta\, sn^2\,\gamma)\frac{sn\,\delta}{cn\,\delta\, dn\,\delta}$$
$$\times \left\{ Z(\lambda) - \frac{k^2\, sn^2\,\delta\, sn\,\lambda\, cn\,\lambda\, dn\,\lambda}{1 - k^2\, sn^2\,\delta\, sn^2\,\lambda} \right\} + 2\pi i Q.$$

The constant $C' = rC$ must be determined so as to make the potential equal to $\varphi = Fx +$ const. at infinity where $\lambda = iK' + \delta$. This leads to the result

$$C' = \frac{4aF\, sn\,\delta\, cn\,\delta\, dn\,\delta}{(1 - k^2\, sn^4\,\delta)^2}$$

in the special case where $\gamma = \delta$ so that the two shells are parts of the same cylinder. For this case we therefore have

$$\chi = \frac{4aF\, sn^2\,\delta}{(1 - k^2\, sn^4\,\delta)} \left\{ Z(\lambda) - \frac{k^2\, sn^2\,\delta\, sn\,\lambda\, cn\,\lambda\, dn\,\lambda}{1 - k^2\, sn^2\,\delta\, sn^2\,\lambda} \right\} + 2\pi i Q.$$

The charge induced upon the shell to the right of the origin can now be expressed,

$$Q = -\frac{aF\, sn^2\,\delta}{K(1 - k^2\, sn^4\,\delta)},$$

and an equal and opposite charge is induced upon the shell to the left.

The ratio of the charge induced on the concave side of the shell to that on the convex side is a measure of the shielding effect produced by the two shells at the same potential. For perfect shielding this ratio is of course zero. At the edge of the shell $\lambda = K + \frac{1}{2}iK'$, and we find, for the charge induced on the concave side of the shell,

$$Q'' = -\frac{aF\, sn^2\,\delta}{\pi(1 - k^2\, sn^4\,\delta)} \left\{ \frac{\pi}{2K} - (1 - k)\frac{1 + k\, sn^2\,\delta}{1 - k\, sn^2\,\delta} \right\},$$

and, upon the convex side,

$$Q' = -\frac{aF\,sn^2\,\delta}{\pi(1 - k^2\,sn^4\,\delta)}\left\{\frac{\pi}{2K} + (1-k)\frac{1 + k\,sn^2\,\delta}{1 - k\,sn^2\,\delta}\right\}.$$

when $k = 0$, $K = \pi/2$, and then $Q'' = 0$. This is the case when the slit between the two shells vanishes so that together they form a complete cylinder.

12. In a field along the y-axis, we have

$$\chi = iCt,$$

and the constant C is to be determined so as to make the potential equal to $\varphi = Fy +$ const. at infinity. In the special case $\gamma = \delta$, we have

$$\chi = \frac{iCp}{sn^2\,\delta}\,\frac{sn^2\,\lambda - sn^2\,\delta}{1 - k^2\,sn^2\,\delta\,sn^2\,\lambda}.$$

After determining the constant, we find

$$\chi = -\frac{i4aFk^2\,sn^2\,\delta\,cn^2\,\delta\,dn^2\,\delta}{(1 - k^2\,sn^4\,\delta)^2}\,\frac{sn^2\,\lambda - sn^2\,\delta}{1 - k^2\,sn^2\,\delta\,sn^2\,\lambda}.$$

From this, we get, for the charge induced on the upper half of the shell to the right,

$$Q_1 = -\frac{aFk'^2\,sn^2\,\delta}{\pi(1 - k^2\,sn^4\,\delta)},$$

and, on the upper half of the shell to the left,

$$Q_2 = -\frac{aF\,cn^2\,\delta\,dn^2\,\delta}{\pi(1 - k^2\,sn^4\,\delta)}.$$

The sum of these is

$$Q_1 + Q_2 = -\frac{aF}{\pi}\,\frac{dn^2\,\delta - k^2\,sn^2\,\delta\,cn^2\,\delta}{1 - k^2\,sn^4\,\delta}.$$

If $\delta = 0$ or K, this is

$$Q_1 + Q_2 = -\frac{aF}{\pi},$$

the same as the charge induced on one-half of a cylinder in a uniform field.

The ratio of the charges induced on the concave to the convex sides of the shell to the right is $k\, cn^2\, \delta/dn^2\, \delta$; the same ratio for the shell to the left is $k\, sn^2\, \delta$, and we therefore have a measure of the shielding effect in a uniform field along the y-axis.

13. In the last problem we again have two cylindrical shells, but their radii are necessarily unequal. Fig. 3 shows

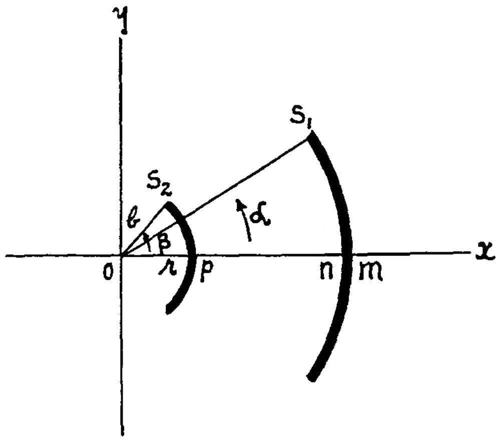

Fig. 3.

the z-plane, and we need consider only the half of it lying above the x-axis. We shall assume $t = 0$ at the origin and $t = \infty$ at infinity. Then we choose the real quantities:

$$0 < r < s_2 < p < n < s_1 < m < \infty,$$

and the differential equation for transforming the w- to the t-plane is

$$\frac{dw}{dt} = \frac{A(t - s_1)(t - s_2)}{t(t - r \cdot t - p \cdot t - n \cdot t - m)^{\frac{1}{2}}}. \tag{58}$$

Since there is a jump of $i\pi$ when we pass from $t = +\infty$ to $t = -\infty$ along a semi-circle of infinite radius, we find $A = 1$; and the jump of $-i\pi$ in w as we pass through $t = 0$ leads to

$$s_1 s_2 = (rpnm)^{\frac{1}{2}}. \tag{59}$$

Using the substitution (3) we find for the solution of (58)

$$w = -2\Pi(\lambda, \delta) + 2\Pi(\lambda, \gamma) - J\lambda + B,$$

where, for abbreviation, we have put

$$J = \frac{2p}{(m-p \cdot n-r)^{\frac{1}{2}}}\left\{1 - \frac{s_1+s_2}{p} + \frac{s_1 s_2}{p^2}\right\}. \tag{60}$$

δ is defined by the equations (6), while for γ we now have

$$\begin{aligned} k^2\, sn^2\gamma &= \frac{r(n-p)}{p(n-r)}, & cn^2\gamma &= \frac{m(p-r)}{p(m-r)}, \\ sn^2\gamma &= \frac{r(m-p)}{p(m-r)}, & dn^2\gamma &= \frac{n(p-r)}{p(n-r)}. \end{aligned} \tag{61}$$

The point at infinity is given by

$$\lambda = iK' + \delta$$

and the origin by

$$\lambda = iK' + \gamma.$$

The conditions to be satisfied are

$$\begin{array}{lllll} t = & m & n & p & r, \\ w = & \log\frac{a}{c} & \log\frac{a}{c} & \log\frac{b}{c} & \log\frac{b}{c}. \end{array}$$

On substitution, we find

$$J = -2Z(\delta) + 2Z(\gamma) - \frac{\pi}{KK'}(\delta - \gamma), \tag{62}$$

$$\log\frac{a}{b} = \frac{\pi}{K'}(\delta - \gamma). \tag{63}$$

In terms of the Theta functions, we can now write

$$\frac{z}{b} = \frac{\Theta(\lambda+\delta)\,\Theta(\lambda-\gamma)}{\Theta(\lambda-\delta)\,\Theta(\lambda+\gamma)}\left(\frac{a}{b}\right)^{\frac{\lambda}{K}}. \tag{64}$$

Let θ be the angle the radius vector to a point on the shell of radius a makes with the x-axis, and on this shell take $\lambda = K + iv$. Then we find, using (63),

$$\theta = \frac{1}{i}\log\frac{\Theta_1(iv+\delta)\,\Theta_1(iv-\gamma)}{\Theta_1(iv-\delta)\,\Theta_1(iv+\gamma)} + \frac{\pi v}{KK'}(\delta - \gamma). \tag{65}$$

If θ' and v' refer to the shell of radius b, so that $\lambda = iv'$ on this shell, we find

$$\theta' = \frac{1}{i}\log\frac{\Theta(iv'+\delta)}{\Theta(iv'-\delta)}\frac{\Theta(iv'-\gamma)}{\Theta(iv'+\gamma)} + \frac{\pi v'}{KK'}(\delta-\gamma). \tag{66}$$

θ vanishes for $v = 0$ and for $v = K'$ and has a maximum value, α, for some intermediate value, v_0. Similarly, θ' vanishes for $v' = 0$ and for $v' = K'$ and has a maximum value, β, for an intermediate value v_0'.

If $\gamma = K - \delta$, so that δ is greater and γ less than $K/2$, we can show that the two angles α and β are equal. Put $\gamma = K - \delta$ in (65) and (66) and we find

$$\theta = \frac{1}{i}\log\frac{\Theta_1(iv+\delta)}{\Theta_1(iv-\delta)}\frac{\Theta(iv+\delta)}{\Theta(iv-\delta)} + \frac{\pi v}{KK'}(2\delta-K), \tag{67}$$

$$\theta' = \frac{1}{i}\log\frac{\Theta(iv'+\delta)}{\Theta(iv'-\delta)}\frac{\Theta_1(iv'+\delta)}{\Theta_1(iv'-\delta)} + \frac{\pi v'}{KK'}(2\delta-K). \tag{68}$$

It follows that the maximum values of θ and θ' are equal to each other since they are determined by the same equation,

$$0 = \frac{\Theta_1'(iv_0+\delta)}{\Theta_1(iv_0+\delta)} - \frac{\Theta_1'(iv_0-\delta)}{\Theta_1(iv_0-\delta)} + \frac{\Theta'(iv_0+\delta)}{\Theta(iv_0+\delta)} - \frac{\Theta'(iv_0-\delta)}{\Theta(iv_0-\delta)} + \frac{\pi}{KK'}(2\delta-K). \tag{69}$$

If the two shells are fairly close together, equation (63) shows that the modular angle must be very small. In this case we can use the first terms only of the expansions of the Theta functions in powers of q. Thus we get for the equation to determine v_0, corresponding to a maximum value of θ,

$$\cosh\frac{2\pi v_0}{K} = -\frac{2\delta-K}{8K'q^2\sin\dfrac{2\pi\delta}{K}}.$$

The right hand term is always positive because δ is greater than $K/2$. For very small modular angles, $K = \pi/2$, and we can determine v_0 from the equation

$$v_0 = \frac{1}{4M}\log\left[\frac{-\left(2\dfrac{\delta}{K}-1\right)\pi}{8K'q^2\sin\dfrac{2\pi\delta}{K}}\right]. \tag{70}$$

where $M = \log e$ and the logarithms are to the base 10. Having determined v_0, $\alpha = \beta$ is found by

$$\alpha = \frac{\pi v_0}{K'}\left(\frac{2\delta}{K} - 1\right) + \tan^{-1}\left\{2e^{-\frac{1}{2}(K'-v_0)}\sin\frac{2\pi\delta}{K}\right\}. \quad (71)$$

13. The transformation of the χ- to the t-plane in the general case when the shell to the left in fig. 3 has a charge Q_2 per unit length at potential 0, and the shell to the right a charge Q_1 at potential V, is given by equations that may be derived from those of Art. 10 by changing the signs of r, p and s; the definition of γ given by equations (61) must be used instead of (45). Equations (54) and (55) are found just as before. The capacity of the condenser formed of the two cylindrical shells is therefore

$$S = \frac{K'}{2\pi K}, \quad (72)$$

and so depends only upon the modulus. This expression is quite general and holds even when the angles α and β are unequal.

In order to show the numerical values involved in these relations the following table has been prepared. The modulus has been taken as $k = 10^{-6}$, and five different values of δ/K have been used. v_0 was calculated from (70) and the angle α from (71). The ratio a/b is given by (63). The last line of the table gives the values of l/d, where $d = a - b$, the distance apart between the two shells, and

$$\frac{l}{d} = \frac{(a+b)\alpha}{a-b} = \frac{\left(\frac{a}{b}+1\right)\alpha}{\frac{a}{b}-1},$$

l being the mean breadth of the two shells.

$k = 10^{-6}$. $K' = 15.2018$.

δ/K	0.55	0.60	0.70	0.80	0.90
v_0	14.003	14.017	14.067	14.170	14.360
α	16° 7′	32° 36′	65° 28′	98° 57′	133° 48′
a/b	1.033	1.067	1.138	1.215	1.297
l/d	17.34	17.53	17.71	17.80	18.06

The capacity of unit length of the condenser formed of the two cylindrical shells is given by (72) and we find

$$S = 1.540.$$

It is interesting to compare this value of the capacity with the value we should get from the simple theory for two parallel plates, neglecting curvature and end effects. This is

$$S' = \frac{l}{4\pi d}.$$

With the values of l/d given in the last line of the table we see that this gives a capacity varying from $S' = 1.379$ to $S' = 1.437$. The difference between the values given by the exact and the elementary theory diminishes as the modulus is diminished.

In order to find the surface density of the distribution of electricity on the conductors, we need to evaluate $d\chi/dz$. In the special case of $\alpha = \beta$, and when the two shells have equal and opposite charges, we find

$$\frac{d\chi}{dz} = \frac{\pi Q}{zK'} \frac{cn\, 2\delta}{sn\, 2\delta\, dn^2\, \delta} \left(\frac{t}{p} - \frac{s_1 + s_2}{p} + \frac{p}{t} \frac{s_1 s_2}{p^2} \right)^{-1}.$$

t/p is given by

$$\frac{t}{p} = \frac{1}{dn^2\, \delta} \frac{dn^2\, \delta - k^2\, cn^2\, \delta\, sn^2\, \lambda}{1 - k^2\, sn^2\, \delta\, sn^2\, \lambda}.$$

We also have

$$\frac{s_1 s_2}{p^2} = \frac{k'^2}{dn^4\, \delta},$$

and

$$\frac{s_1 + s_2}{p} = 2 - \left[4Z(\delta) + \frac{\pi}{KK'} (2\delta - K) \right] \frac{cn\, 2\delta}{2\, sn\, 2\delta\, dn^2\, \delta}.$$

From these expressions the electric intensity may be found at any point and also the surface density at any point of a conductor.

When the two shells are at the same potential, a charge given to them divides in the ratio

$$\frac{Q_1}{Q_2} = \frac{\delta/K}{1 - \delta/K}.$$

In the limit, when $\delta = K$, and the shells are complete cylinders, the charge on the inner one, Q_2, of course vanishes. The charge on the outer of the two shells is always the greater, since δ is greater than $K/2$.

14. When the system of the two shells is placed in an electric field along the x-axis we have to solve equation (58) after changing the signs of r, p and s''. The analysis follows along the same lines as in Art. 11. As far as shielding effects are concerned the results are very similar to those obtained in the first problem, which differs from the present one in having a complete cylinder inside instead of a cylindrical shell. Similar remarks apply to the case of a field along the y-axis.

The methods that have been used in solving these problems could, with some advantage, be used in the problem of the two cylinders at a distance, or the intersecting cylinders.[1] By taking $t = \infty$ at $z = \infty$ we do away with the necessity of using the auxiliary t'-plane that was needed in the previous paper. Alternatively, as will be shown later, a different substitution of the first order may be used to obviate the necessity of using the auxiliary t'-plane.

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[1] *Proc. Am. Phil. Soc.*, LXXV, 1935, p. 11.

IONIC SILVER FROM SILVER HYDROXIDE AS A THERAPEUTIC AGENT

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ABSTRACT

Certain peculiar characteristics of silver oxide in comparison with the more clearly known properties of colloidsl metallic silver and the numerous salts of this metal recognized in medical practice have prompted the study of silver oxide from a therapeutic standpoint.

Anhydrous silver oxide is dispersed in an inactive carrier consisting of a mixture of saturated aliphatic hydrocarbons and this quite stable dispersion is proposed as a new means of introducing the active silver ion into the animal system. Such a dispersion when brought in contact with animal membranes or lesions thereon acts as a reservoir from which a continuous flow of the appreciably soluble and mildly alkaline hydroxide of silver can take place.

Considerable animal experimentation and actual clinical work seem to indicate that this new silver preparation possesses all of the antiseptic and disinfective properties commonly ascribed to well known silver compounds but is of distinct advantage in as much as the hydroxide of silver is entirely free from causticity or irritant effect upon the most delicate mucosa. Internal administration in large doses and absorption of silver in this form by continued inunction fail to disclose any toxicity and at the same time show that danger of accidental localization of metallic silver or production of an argyria is removed or at least minimized.

FOR MANY years the salts of silver and certain complex mixtures containing the colloidal metal have been known to possess therapeutic properties and of the numerous preparations so applied, the simple salts of the metal represent the older group. The silver salts, themselves fall into two classes —those which are quite soluble and have decided causticity and destructive action on living tissues, and a number of slightly soluble salts which by their limited concentration in water exert little or no caustic action while still retaining some of the beneficial effects supposed to be due to the silver ion.

The relatively insoluble silver salts, of which the chloride and iodide are examples, have been put to medical use as colloidal dispersions in various inactive carriers so as to facilitate the absorption of the otherwise inactive compound.

Preparations which contain essentially the colloidal metal

are of more recent origin and have been developed largely because the simple salts of the same metal are not free from certain objectionable properties connected with their destructive action on delicate mucous membranes and attended danger of localization of reduced metal in or about the treated areas. Perhaps the fear of producing an accidental argyria of localized or diffuse type has been the main cause of the very guarded way in which silver compounds have been medically prescribed.

All of the colloidal metallic silver preparations, official and otherwise, have one point in common—that is the colloidal metal itself as essential constituent, but they vary greatly as to the organic complex which has been used in the reduction of the initial silver compound. It should be noted, however, that these mixtures are indefinite in composition and contain not only colloidal metallic silver but complex silver proteins, albuminoids, and other products obtained by the interaction of silver salts with such complexes as albumin, casein, etc. commonly used to effect the reduction to colloidal metal. From a purely chemical standpoint it will be seen that the use of the colloidal metal owes its advantage to the disappearance of caustic activity of the silver salt but this improvement is gained only by the complete or nearly complete loss of silver ion concentration in the product. Admittedly the colloidal metal particle cannot function as a true solute and therefore cannot be expected to penetrate cellular structures or other semi-permeable membranes to any extent. This if true would certainly suggest that much of the bactericidal power known to be characteristic of the silver salts has been thrown aside in order to make the less restricted use of silver preparations safe.

It is observed that various degrees of physiological activity exhibited by salts of silver depend upon two main factors—the solubility of the salt and, what appears to be of equal importance, the strength of the acid from which the silver salt is derived. In brief, the increase in solubility and the increase in acid strength both contribute to the instability

of a silver salt when the same is in contact with organic material. When decomposition takes place a silver salt splits off metallic silver and simultaneously generates a free acid as oxygen is taken up by the organic complex. Destructive action upon delicate membranes, it may be argued, is then due chiefly to this acid influence, for it is well known that normal cellular growth can take place only in a mildly alkaline medium comparable to blood plasma. Aside from the caustic effect due to accumulation of the acid product of decomposition it is evident that the staining due to simultaneously deposited metal proceeds with increasing activity as acid accumulates, and that various degrees of argyria are brought about by the same conditions that regulate the rapidity of the silver salt decomposition.

From the above considerations it would appear that if the full bactericidal power of a silver compound is to be experienced with safety no compound containing an acid anion could be expected to fully exert this action.

The purpose of this paper is to show that it seems quite possible to make therapeutic use of the silver ion under conditions in which the environment is continuously alkaline and thus bring the silver ion itself into pronounced activity without the limitations imposed upon the use of silver salts or without falling back on the mild but comparatively inactive metallic silver colloids.

Silver Oxide and Silver Hydroxide

Silver oxide is ordinarily thought of as a brown insoluble powder, precipitated from solutions of silver salts by addition of the caustic alkalies, but as a matter of fact the oxide is appreciably soluble in pure water with formation of the hydroxide. The solubility of the oxide in pure water has been imperfectly studied and such values obtained from the literature are in poor agreement. These run considerably above and below an average of 0.0215 g. per liter at 20° C.

Experiments were made to fix this solubility with reasonable accuracy. For this purpose the finely divided oxide was

precipitated from dilute cold solution of the nitrate in freshly distilled water. The precipitate was thoroughly washed with large amounts of water to remove the other products of the reaction. An excess of the oxide was then actively agitated with water for thirty-six hours or more under thermostatic control at 15° C.

The filtrate upon analysis showed the presence of 0.0306 g. Ag_2O per liter. This indicates a solubility of approximately twenty times that of silver chloride. Attempts to repeat the experiment using water containing small amounts of carbon dioxide absorbed from the air showed that even small amounts of this gas decidedly affect the solubility. With this in mind the carbonate of silver was prepared and shaken with water under the same conditions of temperature as the oxide. Results showed that the carbonate dissolved to the extent of 0.0474 g. per liter which is the equivalent of 0.0398 Ag_2O.

The experiment was repeated but this time the solution was kept saturated with carbon dioxide. Analysis gave still greater solubility and corresponded to 0.163 g. per liter Ag_2O. This increase in solubility is explained by the formation of a silver acid carbonate which salt as such has never been isolated.

In explanation of the above comparison of oxide and carbonate it should be said that any solution of the oxide put to practical use might contain quantities of the oxide anywhere between the above limits but the point of interest is that the minimum value is such that the solubility is at least twenty times that of the chloride.

In regard to the carbonate, more or less of which will be formed when the oxide is digested with ordinary distilled water it may be assumed that approximately the same degree of alkalinity will be obtained as if the oxide had been dissolved in carbon dioxide-free water. This follows from the almost complete hydrolysis of the silver salt of the feeble carbonic acid at high dilution. While this statement is not strictly accurate, it is true in a biological sense as indicated by the almost similar values obtained for the pH of saturated solutions of both oxide and carbonate.

These pH values determined by the indicator method on solutions of the oxide and carbonate at 15° C. were as follows:

Saturated solution of Ag_2CO_3 containing 0.0474 g. Ag_2CO_3 per L. pH 8.5.
Saturated solution of Ag_2O containing 0.0306 g. Ag_2O per L. pH 8.4.

Silver hydroxide has been precipitated as a white gelatinous mass by precipitation in the cold from very dilute solution (0.01 N. silver nitrate) but this compound rapidly parts with water leaving the brown oxide. On the other hand the water solution at saturation is remarkably stable even in the presence of bright light. If preserved from outside contamination it can be kept for long periods without the least change.

Even at saturation the solution of silver hydroxide is too dilute to expect much therapeutic effect unless comparatively large volumes are administered, but the writer believes that this difficulty may be overcome in a simple way—that is by preparation of an anhydrous dispersion of the pure oxide of silver in an inactive carrier such as the saturated aliphatic hydrocarbons in which the content of silver oxide may be varied within any reasonable limits and then administer this dispersion so as to allow the continuous absorption of the product of hydration of the dispersed oxide particles to take place. In other words it is proposed to use the completely anhydrous system of silver oxide and inactive hydrocarbon as a reservoir from which almost any desired amount of silver hydroxide can be continuously withdrawn when contact with aqueous tissues, mucous membranes, etc. is established.

The migration of the silver oxide from its oily carrier into the aqueous medium with which it is brought in contact is interesting in several ways: First the velocity of movement of the silver oxide is greatly affected by the size of the colloidal oxide particle. An ordinary mixture of the precipitated oxide with paraffin oil is relatively inactive but it has been found that subdivision of the oxide to a particle size of 1 micron or

thereabouts results in an active dispersion which quickly yields its oxide to any medium where hydration can take place. Secondly the equilibrium between silver oxide in its oily carrier and the hydroxide formed by contact with water-bearing structures as expressed by the equation—

$$Ag_2O + H_2O \rightarrow 2Ag(OH) \leftrightarrows 2Ag^+ + 2(OH^-)$$

is characterized by a one directional flow of ionized silver toward the aqueous medium in contact with the dispersed oxide. This means that when silver hydroxide is formed at the line of contact a true solute is formed which is incapable of return to the oily carrier and for this reason the hydration of oxide is continuous and living tissues exposed to the colloidal oxide are likely to remain saturated with the mildly alkaline base Ag(OH) as long as the oily reservoir of colloidal oxide lasts.

It should not be overlooked that because the saturated water solution of silver oxide is mildly alkaline (pH 8.4), it is incapable of disturbing the normal pH of blood plasma in contradistinction to the effect of the salts of silver in general, and that if any decomposition of the hydroxide should occur by some reducing influence the products of such a breakdown could be only silver, oxygen, and water.

The statement that silver hydroxide is non-toxic and harmless to delicate membranes and normal cellular structures is made, but only after a thorough clinical investigation carried out through the much appreciated co-operation of Dr. William J. Lentz of the Department of Veterinary Medicine of the University of Pennsylvania. Under the direction of Dr. Lentz the colloidal oxide dispersions have been used upon a long series of animals in which excessive doses were purposely applied. Administration was made by inunction, intraperitoneal injection, through the stomach and lower intestine. The dispersed oxide has also been used upon the eyelids, cornea, and likewise in the urethral and vaginal cavities and in a number of cases of ear abscess and in many lesions of ulcerative and suppurative type. Several hundred one day

old chicks were raised under circumstances where all drinking water was substituted by the saturated solution of silver hydroxide.

In all of these cases no systemic indications of toxicity or irritating effect were observed.

It is well known that one of the serious objections to silver therapy in general is the danger of accidental localization of metallic silver, an argyria, but here again certain properties characteristic of silver hydroxide appear to advantage when compared to any salt of silver known to medical practice. The following experiments are significant. Starting with a five per cent silver oxide dispersion, samples approximating 1 to 1.5 grams were rubbed into the normal skin of the hand daily for many months; no staining effect occurred on or about the area treated. Similar treatment with a dispersion of a slightly soluble silver salt containing the equivalent of silver resulted in a permanent dark stain after three or four applications.

With the purpose of provoking an argyria if possible the five per cent silver oxide colloid was administered by inunction over the entire surface of the skin of dogs. Daily treatment in this way with abnormally large amounts of the dispersion over long periods also failed to cause any visible deposition of the metal and likewise gave no sign of toxic effect.

Six albino guinea pigs, males, averaging 500–600 grams were selected and after shaving the hair from their backs to expose about four centimeters square of skin per animal, definite amounts of the oily dispersion were rubbed in three times daily until each animal had absorbed 250 milligrams of silver oxide. In less than twenty-four hours qualitative analysis of both urine and feces gave strong tests for silver. The surface of the skin was then carefully washed off with alcohol and after destroying the animal the treated skin areas were removed. These were treated first with formalin and then with a solution of sodium sulphide. Microscopic examination of the epidermis failed to disclose the least trace of silver which would have been easily visible after sulphiding

had it been present. To make sure of the absence of silver the skin samples were then repeatedly evaporated with concentrated sulphuric acid in presence of nitric acid and the clear solutions ultimately obtained were examined for traces of silver in the usual way. Results were negative. As a check, a control animal was treated with a dispersion of silver acetate in oil containing the same amount of silver as the oil dispersion of oxide in the previous experiments. In this case the deposition of some free silver in the skin was so pronounced that it was scarcely necessary to sulphide the skin to make the deposited silver visible.

These experiments show plainly that the dispersed oxide is unquestionably absorbed through the normal skin of the living animal and the presence of silver in both urine and feces indicates a diffuse systemic absorption even when the material is administered by inunction. In the case of the control animal, which had been treated with silver acetate, silver was also found in the urine and fecal discharge but evidently the total amount was not so eliminated as measurable amounts of the metal were found as a permanent deposit in the epidermal cells.

From the chemical nature of silver oxide or its hydroxide it would seem probable that continued contact with organic tissues would result in the split off of metallic silver and water as the oxygen is taken up by oxidizable organic complexes but if any such behavior does take place the reaction velocity must be such that no visible signs of its occurrence are observed. The writer believes that the systemic absorption without concurrent deposition of silver can take place because of the mildly alkaline (pH 8.4) nature of silver hydroxide and its similarity in this respect to the normal environment of living cells. In addition the concentration of active silver hydroxide is limited by its moderate solubility and permits complete penetration and still further dilution in the aqueous fluids of the system before deposition of metal can occur.

The non-aqueous dispersion of silver oxide in paraffin oils represents an effective means of preventing any decomposition

of the otherwise unstable oxide and assures the liberation of the hydroxide only at the line of contact of the dispersion with the aqueous tissues or lesions to which it is applied.

Silver hydroxide differs from any salt of silver because it contains nothing but water and oxygen as anodic products. This is in marked contrast to the behavior of any salt of the same metal which could not break down in presence of organic matter without production of a liberated acid. The following equilibria express the distinction clearly:

$$(1)\ Ag_2O + H_2O \rightleftharpoons 2Ag(OH) \rightleftharpoons 2Ag^+ + 2(OH^-)$$
$$2Ag^0 + H_2O + O^0,$$
$$(2)\ 2Ag(C_2H_3O_2) \rightleftharpoons 2Ag^+ + 2(C_2H_3^-O_2) + H_2O$$
$$\rightarrow 2H(C_2H_3O_2) + 2Ag^0 + O^0$$
$$\downarrow\uparrow$$
$$2H^+ + (C_2H_3^-O_2).$$

In each equilibrium the reaction will be shifted toward the right by any reducing influence as oxygen is so removed.

Equation (1) shows that the only possible products are silver and water. In equation (2), in which the acetate is taken as an example of a simple silver salt, it is quite obvious that the end products are silver and a free acid and needless to say the dissociation of the latter is a measure of the rise in hydrogen ion produced. This rise in hydrogen ion will of course speed up the further reduction of the salt with resulting localized deposition of silver, thus favoring an argyria. At the same time the sharp drop in pH brought about by the liberation of an acid causes caustic action and destroys normal cell structures to a degree measured by the strength of the acid from which the silver salt is derived.

The whole system expressed by equation (1) is alkaline and assuming complete reaction to the right, cannot go to a lower pH than that expressed by neutrality. Now as blood plasma is itself slightly alkaline it is obvious that the dispersed silver oxide applied to any lesion will continuously supply and maintain an alkaline influence and if antiseptic or disinfective effects result, such must be due only to the action of the silver ion itself.

Bactericidal Action of Dilute Solutions of Silver Hydroxide

While silver salts and perhaps some of the colloidal dispersions of the metal are believed to be of value as bactericidal agents nothing is known concerning the activity of silver hydroxide in this respect. The following preliminary experiments were carried out with the saturated solution of silver hydroxide in direct comparison with the well known active disinfectant mercuric chloride at a 1 to 10,000 dilution.

The regular procedure for determination of the phenol coefficient was modified because of the high sodium chloride content in the culture medium (0.5 per cent), but a special medium was used in which only 0.019 per cent NaCl was present in the beef extract. This was employed in the following tests to compare the bactericidal action of the saturated silver hydroxide solution directly with a 1 to 10,000 mercuric chloride.

5 cc. each of the undiluted solutions and the same volume at the following dilutions—(1 : 2; 1 : 4; 1 : 6; and 1 : 8) were mixed with 0.5 cc. of a twenty-four hour culture of staphylococcus aureus at 37° C. and after periods of 5, 10, 15 and 30 minutes contact of material and organism, a transplant of a standard loopful of the mixture was made into 10 cc. of bouillon. After 48 hours' incubation the results were obtained as shown in Table 1.

Agar Cup Method

Further comparison of the saturated solution of silver hydroxide with 1 to 10,000 mercuric chloride was made by mixing 15–20 cc. of melted agar, cooled to 45° C., with 0.1 cc. of a twenty-four hour culture of Staphylococcus aureus, pouring the mixture into a Petri dish and allowing to harden. When hard (2 to 3 minutes), a piece of agar 1.5 cm. in diameter was cut from the center, leaving a cup into which six drops of the solutions to be tested were placed. After twenty-four hours' incubation the plates were examined for areas of no growth and from these clear areas, in which either bactericidal

TABLE 1

BACTERICIDAL ACTION OF SILVER HYDROXIDE

Concentration of Silver Oxide in Pts. Ag_2O per 10,000 Pts. Water	Minutes Exposure of Mixture to Organism, Staphylococcus aureus			
	5	10	15	30
1.63 (saturated)	neg.	neg.	neg.	neg.
0.815	neg.	neg.	neg.	neg.
0.407	pos.	pos.	neg.	neg.
0.271	pos.	pos.	pos.	neg.
0.203	pos.	pos.	pos.	neg.
Concentration of Mercuric Chloride Parts per 10,000	**Minutes Exposure of Mixture to Organism, Staphylococcus aureus**			
	5	10	15	30
1.00	neg.	neg.	neg.	neg.
0.50	neg.	neg.	neg.	neg.
0.25	neg.	neg.	neg.	neg.
0.166	pos.	neg.	neg.	neg.
0.125	pos.	neg.	neg.	neg.

or bacteriostatic effect must have taken place, small pieces of agar were taken at known distances through the clear zone. These transplants were incubated for 48 hours in bouillon at 37°. The tabulated results show the extent of bactericidal action in ratio to the total area of no growth.

AGAR CUP METHOD

Solutions	Width of Clear Zone	Distance for Sub-culture	Growth or No Growth
Silver hydroxide, containing 1.63 pts. Ag_2O per 10,000 pts. water	2 to 4 mm.	1 mm.	neg.
		2 mm.	neg.
		3 mm.	pos.
Mercuric chloride, 1 pt. $HgCl_2$ per 10,000 pts. water	6 mm.	2 mm.	neg.
		4 mm.	neg.
		5 mm.	neg.
		6 mm.	pos.

Inspection of the above tables shows that solutions of silver hydroxide do not have the full bactericidal effect possessed by

mercuric chloride at comparable concentrations, as would be expected in the first place, but there is evidence that the saturated silver hydroxide solution, containing 163 milligrams of silver oxide per liter, or solutions of the same at half this concentration, are effective in the destruction of Staphylococcus aureus within the narrow time limits required for the toxic solutions of mercuric chloride to do the same work. This together with the non-poisonous and non-irritating nature of silver hydroxide, which extended clinical work seems to establish, is enough to make a careful medical study of silver oxide worth while.

A more thorough study of the bactericidal action of silver oxide in comparison with various preparations containing colloidal metallic silver is certainly suggested by these preliminary tests as well as by actual clinical experience in the treatment of certain pyogenic infections and when completed will appear in a separate paper.

The writer is indebted to Dr. Ruth Miller for her co-operation in the determination of the bactericidal action of silver hydroxide and to the courtesy of the Laboratory of Bacteriology, University of Pennsylvania where these experiments were made.

Preparation of Colloidal Silver Oxide

Colloidal dispersions of silver oxide, designed specially for clinical use, were obtained as follows:

Silver oxide was precipitated from dilute water solutions of the nitrate in the cold by addition of sodium hydroxide. The finely divided precipitate was washed free from soluble products and filtration made by suction to remove as much water as possible. The brown mass of oxide was dried in air ovens at 110–120° C. with careful exclusion of dust or other reducing influences. The dry oxide was then mixed with three times its weight of low viscosity paraffin oil and the mixture subjected to the prolonged action of a colloid mill.

Pebble milling was continued for periods of three or four weeks to bring the subdivision of the silver oxide particles well

beyond the limit required for no settling effect in thin oil mixture.

Particle size was roughly determined from time to time by withdrawing samples and observing the rate of fall of the oxide in thin oil of known viscosity and fixed temperature. It was observed that a kilo of silver oxide with three parts of thin oil required approximately three weeks of continuous milling to reduce the silver oxide particles to an average size of about one micron.

After four weeks the finished product was more carefully examined by micrometric determination. The micro-photograph below (Fig. 1), shows the relative size of the dispersed

FIG. 1. Microphotograph of dispersed silver oxide particles compared with normal red blood cells. Magnification 550 diameters.

particles in comparison with normal red blood cells photographed in the same field. Magnification 550 diameters. During the milling process a simple test for the required subdivision of the oxide was found. This test was made by rubbing a half gram sample upon the skin of the hand. In finer dispersions ready for use the dark colored oxide particles passed through the skin leaving only the inert pale yellow oily carrier on the surface but in the case of less complete milling, particles of the oxide were held back by the skin

because of a simple filtration effect with production of a dark stain lasting for some hours.

On the basis of the rapid absorption of all of the silver oxide by simple inunction upon the normal skin, it was found that kilo lots of silver oxide mixed with three times its weight of paraffin oil could be adequately dispersed in about three weeks' milling.

The fully milled oil dispersions so obtained were used as a stock from which large quantities of more dilute mixtures could be rapidly made by mixing with the calculated amounts of hydrocarbon carrier. For nearly all clinical work a five percent dispersion was used and control of viscosity of the final product was secured by selection of the appropriate grade of heavier or lighter hydrocarbon mixture for dilution of the stock dispersion.

The saturated aliphatic hydrocarbons seem to be the only inert media in which silver oxide can be dispersed with complete assurance of stability. Such dispersions have been found unchanged in composition over several years even in the presence of light and very probably owe their stability to the non-aqueous character of the components as well as to the chemical inactivity of the paraffins.

A five per cent dispersion of the oxide will permanently stain cloth, bandage, clothing, etc. but will not discolor the skin or living membranes to which it is applied if the dispersion is properly made. The preparation should not be brought in contact with surfaces which have been recently treated with phenolic compounds, glycerine, essential oils or other oxidizable organic compounds which promote a deposition of metallic silver before absorption is completed.

It is of interest that silver oxide has received little or no attention from a therapeutic standpoint and that a colloidal dispersion of the oxide in an inactive carrier has not been hitherto made. Examination of the literature shows that the oxide was once used as a starting product for the manufacture of a certain complex mixture containing chiefly the colloidal metal. This preparation found among non-official remedies

was prepared by mixing silver oxide with a solution of casein and then evaporating to dryness or near dryness on a water bath. The brownish black residue was then dissolved in water. By some unusual disregard of chemical incompatibilities the resulting product was referred to as a colloidal silver oxide. A moment's consideration, however, makes it plain that such a mixture could not contain silver oxide colloidal or otherwise and that contact with casein even in the cold would result in reduction of the oxide to the metal together with the formation of various silver proteins, etc. From this it follows that colloidal silver oxide has never been medically used and finds no justifiable mention in the literature of medicine or pharmacology.

Systemic Absorption of Silver Oxide and Elimination of the Same from the Animal System

It has already been stated that an oily dispersion of anhydrous silver oxide containing five per cent silver oxide will yield its entire silver oxide content to the animal system by simple inunction on the surface of the skin or by application to open lesions or mucous surfaces and that when so absorbed, silver in some form or other can be readily found in both urine and feces of the treated animal. The analysis of the skin and underlying tissues of animals treated by inunction failed to show any sign of deposits of silver or any compounds of this metal so that complete systemic distribution of the administered oxide is more than probable.

The following experiments were carried out to determine quantitatively the elimination of silver in both urine and feces.

Animals used: Male guinea pigs of approximately 550 grams.

These animals were prepared for administration of the colloidal oxide oil dispersion by shaving the hair from their backs over an area of about four or five centimeters square. Administration of the dispersion was made by inunction in the exposed skin areas of a definite weight of the five per cent dispersion through the use of rubber finger cover. Actual weight

of the dispersion used together with the known weight of silver oxide therein contained is given in the tables below. The animals were kept in separate special cages which were furnished with sloping glass bottoms so slotted and inclined as to allow a reasonably accurate collection of separate samples of urine and feces from each animal after treatment with the colloidal oxide. The collection of fecal matter was made at frequent intervals so as to avoid contamination on the floor of the cages by liquid excreta and separate analyses were made daily of the total urine and total fecal matter obtained in each twenty-four hour period. The method of analysis was briefly as follows.

For silver in feces: Each 24-hour yield was dried and then ignited to ash in porcelain crucibles, taking care to avoid temperatures high enough to fuse the ash into the glaze of the container. The gray ash containing small amounts of unconsumed carbon was first extracted with nitric acid to remove the major portion of the silver. The insoluble residue containing compounds of silver which had escaped reduction by partial ignition of the organic material were extracted with ammonium hydroxide and the combined filtrates from both acid and ammoniacal extractions were reduced to small volume followed by precipitation of silver as chloride.

Recovery of silver from urine samples: These samples in twenty-four hour yields were evaporated to small bulk in beakers of clear quartz and subsequently treated with concentrated sulphuric and nitric acids to destroy most of the organic matter. Frequent evaporation with addition of more nitric acid was followed by introduction of potassium acid sulphate and final ignition made until the major part of the residual sulphuric acid had been fumed off. The solid or semisolid residues containing mostly potassium sulphate and all of the silver as sulphate were dissolved in water and filtered to remove traces of insoluble siliceous matter. Silver was recovered from these filtrates as chloride and weighed as such.

Tables A and B with their corresponding graphs *A* and *B* indicate the separate daily yields of silver recovered from both

TABLE A

Guinea Pig A

Male. Weight 570 grams. Dose given in four portions by inunctions. Administered in first 24 hours. Total weight of ointment 4.0 g. containing 0.200 g. Ag_2O

Date of Collection of Samples	Silver Recovered from Urine and Feces. Weighed as Silver Chloride and Calculated to the Equivalent of Ag_2O	
	Recovered from Urine—Grams Ag_2O	Recovered from Feces—Grams Ag_2O
12/ 6.34	0.0005	0.0000
12/ 7	0.0005	0.0055
12/ 8	0.0010	0.0084
12/ 9	0.0007	0.0240
12/10	0.0006	0.0175
12/11	0.0007	0.0151
12/12	0.0008	0.0136
12/13	0.0008	0.0087
12/14	0.0000	0.0045
12/15	0.0005	0.0126
12/16	0.0003	0.0117
12/17	0.0001	0.0043
12/18	0.0004	0.0054
12/19	0.0008	0.0033
12/20	0.0004	0.0040
Total	0.0077	0.1386

Total elimination of Ag_2O from animal—0.1463 or 73.15 per cent of the 0.2000 g. Ag_2O administered.

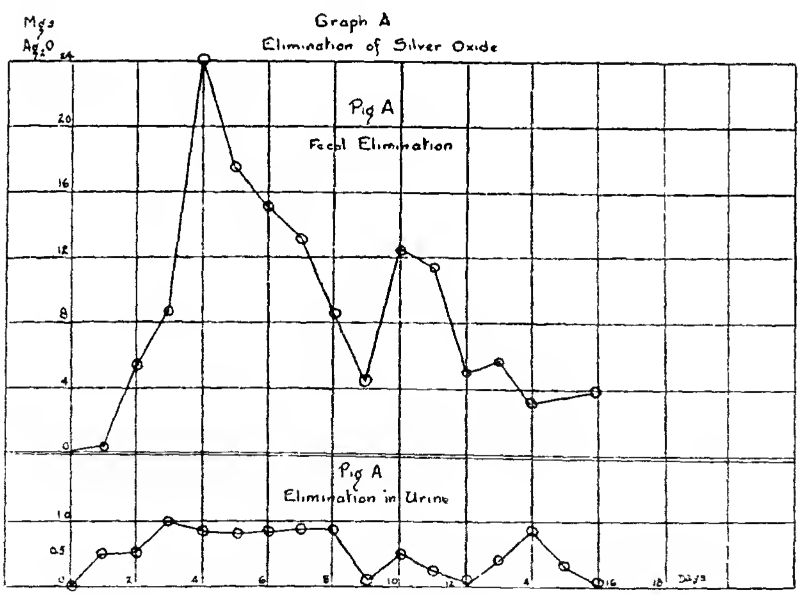


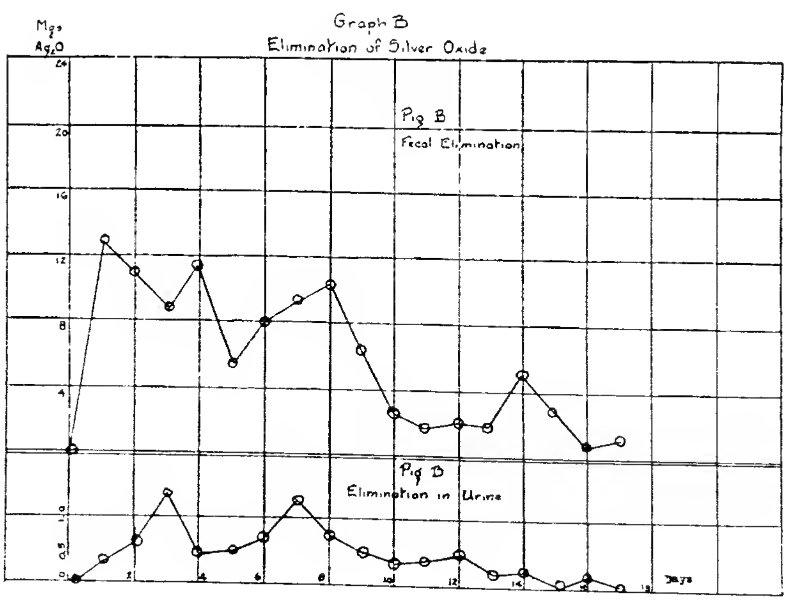
TABLE B

GUINEA PIG B

Male. Weight 540 g. Dose given in two portions by inunction. Administered in first twenty-four hours. Total weight of ointment 2.7 grams, containing 0.135 g. Ag_2O. 1/15/35.

Date of Collection of Samples	Silver Recovered from Urine and Feces Weighed as Silver Chloride and Calculated to the Equivalent of Ag_2O — Ag_2O from Urine	Ag_2O from Feces
1/16/35	0.0003	0.0130
1/17	0.0007	0.0110
1/18	0.0015	0.0088
1/19	0.0004	0.0118
1/20	0.0004	0.0057
1/21	0.0008	0.0080
1/22	0.0013	0.0093
1/23	0.0007	0.0102
1/24	0.0005	0.0066
1/25	0.0003	0.0027
1/26	0.0003	0.0019
1/27	0.0005	0.0021
1/28	0.0002	0.0019
1/29	0.0002	0.0053
1/30	0.0000	0.0024
1/31	0.0003	0.0007
2/ 1	0.0000	0.0012
Total	0.0084	0.1026

Total elimination from animal Ag_2O—0.1110 or 82.6 per cent.



feces and urine over periods of sixteen to twenty days (Animals A and B).

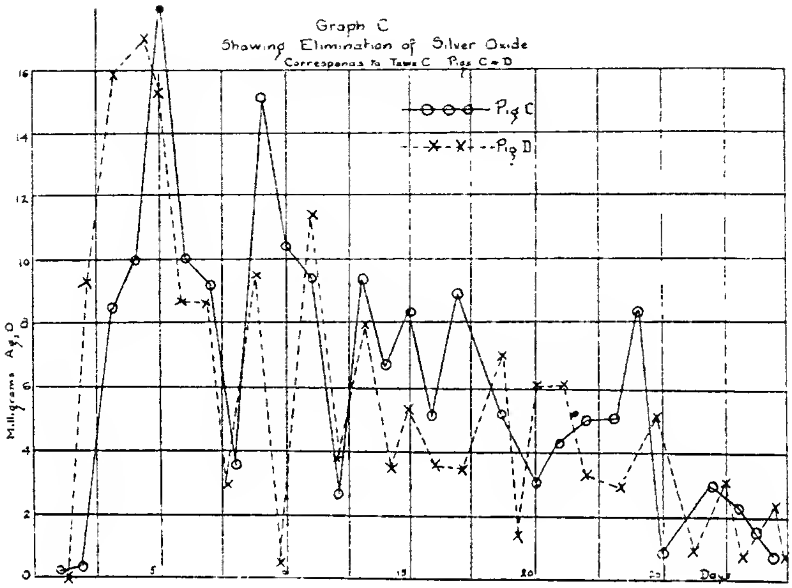
Table C with Graph *C* gives results for two animals, C and D, but as the elimination through the urine was shown to be small compared with that found in the fecal discharge the results are here tabulated in daily elimination from combined urine and feces samples of these two animals. These analyses

TABLE C

GUINEA PIGS C AND D

Dose, 0.2000 gram. Silver oxide dispersion administered to each animal by inunction. Weight of C—590 g. Weight of D—530 g.

Days	Pig C Grams Ag_2O Recovered from Urine and Feces	Pig D Grams Ag_2O Recovered from Urine and Feces
1	0.0000	0.0000
2	0.0002	0.0093
3	0.0085	0.0160
4	0.0100	0.0170
5	0.0183	0.0153
6	0.0100	0.0087
7	0.0093	0.0087
8	0.0036	0.0030
9	0.0153	0.0097
10	0.0105	0.0006
11	0.0094	0.0114
12	0.0026	0.0032
13	0.0094	0.0080
14	0.0067	0.0035
15	0.0082	0.0052
16	0.0050	0.0036
17	0.0090	0.0035
18	0.0051	0.0070
19	0.0030	0.0015
20	0.0042	0.0060
21	0.0050	0.0062
22	0.0050	0.0033
23	0.0083	0.0030
24	0.0009	0.0052
25	0.0003	0.0013
26	0.0030	0.0030
27	0.0021	0.0008
28	0.0018	0.0027
29	0.0009	0.0002
30	0.0010	
31	0.0005	
Total Ag_2O	0.1771 or 88.55%	0.1669 or 83.45%



were carried over a longer period so as to reach the practical limit for the accurate determination of silver as chloride.

Absence of silver in the organs of excretion: At the end of about five weeks from the initial dose of 0.2000 g. for each animal, guinea pigs C and D were killed and the liver and kidneys of each were separately analysed for silver. For this purpose the organs were dried and carefully ignited in quartz vessels to destroy the major part of the organic matter, taking great care to not heat to fusion against the quartz surface. Complete decomposition was now effected by fuming down with a mixture of concentrated sulphuric acid and nitric acid with final fuming with sulphuric acid and several grams of potassium acid sulphate. The residual acid sulphate melts were dissolved in water and saturated with hydrogen sulphide. This treatment which would have disclosed the minutest quantity of silver detectable by precipitation failed to show silver in both kidneys and liver of these animals.

Search for silver in the treated skin areas of these animals also gave negative results.

Tables A and B with their corresponding graphs show the recovery of 73.15 per cent and 82.60 per cent of the total dosage of colloidal silver oxide administered by inunction to animals A and B respectively, and with due consideration of the difficulties experienced in determining small amounts of silver in large masses of organic matter such results point to a probable complete elimination of silver from the animal system. A and B also show that elimination in the fecal discharge greatly exceeds that in the urine. The ratio of recovered silver from these sources is roughly twenty to one. These experiments were discontinued at the end of about eighteen days but plainly point to a probable complete elimination in a period of approximately thirty days.

In order to increase the accuracy of determining the total silver eliminated and to cut down the errors due to a large number of separate analyses guinea pigs C and D were treated in a similar manner, but recovery of silver was made from combined urine and feces samples from each animal, carrying the daily analyses of collected excreta over a much longer period. In these cases the total yields of recovered silver from C and D were 88.55 per cent and 83.45 per cent of the administered 0.200 gram silver. These large percentages together with the negative tests for silver in both kidneys and liver and total absence of silver in the skin and underlying tissues at the place of administration certainly point to a probable completeness of elimination from the animal system, and at the same time prove beyond question that inunction upon the normal skin is rapidly followed by complete systemic absorption of all of the silver oxide present in a five per cent dispersion.

It must be acknowledged that the precise manner in which silver oxide is carried into the animal system and discharged by the organs of excretion is far from clear, but it would seem entirely reasonable to explain the rapid migration through the skin or superficial membranes by assuming a continuous hydration of the mobile minute particles of oxide in the inert hydrocarbons by their contact with water bearing tissues.

Such hydration must produce a unidirectional flow of silver ions because the hydroxide is a true solute which cannot come back into the original oily reservoir of oxide.

It is well known that the fluids of the body, blood plasma, etc. contain much chloride and it is a little difficult to see how the silver hydroxide would escape conversion to chloride and partial deposition as metal by reducing influences, but aside from clinical evidence to the contrary there are good chemical reasons for believing that silver introduced into the system in this way is not converted to chloride or reduced to the metallic state. In the first place silver oxide only slowly hydrates at the point of contact with watery tissues and owing to its slight solubility the base Ag(OH) is completely dissociated, giving a mild alkaline solution which is swept into the system and diluted therein before chloride can separate or any reducing effect can be found. Now as the natural environment in which normal cell growth can take place is itself mildly alkaline, it will be seen that highly diluted silver hydroxide which is also basic will allow complete distribution without precipitation of chloride or deposition of the metal.

To bear out the above suppositions it has been repeatedly noticed that absorption of silver oxide will not take place through the skin or exposed membranes of a dead animal—evidently because there is no underlying circulation. Such surfaces are invariably stained by deposited silver and only absorb small amounts of the colloid. Throughout the fairly extended clinical application of the colloidal oxide during the past several years it has also been noted that the treatment of badly infected lesions containing much pussy detritus results in formation of some staining due to deposition of silver, but in every case the mechanical cleansing of such lesions disclosed the presence of metal only in the dislodged detritus and not in the living cell structures beneath. This again shows that decomposing dead material, generally of an acid nature, speeds up a reduction of the oxide while the normal tissues fail to exert such a decomposition.

Case reports and particular discussion of clinical work are

out of place in this paper and out of the field of the writer's investigation, but it may be safely said that silver oxide in colloidal form can be successfully used as a general antiseptic and disinfectant free from toxic effect or irritating action. Survey of all of the clinical results so far obtained will also disclose the fact that its most probable field of usefulness will be in the treatment and control of the secondary invaders and infections of a pyogenic nature.

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EARLY MAN IN AMERICA

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(*Read April 25, 1936*)

Abstract

In attempting to evaluate the evidence regarding the length of time man has been in the New World, and by what route he came, one must recognize what an important role speculative interpretation has played, and try to give such evidence the place it deserves, without overemphasis. There are a good many facts that have come to light, especially during the last decade, which, while they do not give us complete answers to our queries, at least, they lead us in the path, by which it is hoped a solution of the problem of man's antiquity in America eventually will be found.

It is with some misgiving that I undertake to discuss a subject that has involved so much controversy for fifty years or more. However, since new light has been shed upon it in the last few years, it may not be amiss to consider at this time how the problem of man's antiquity in the New World stands today, even though some of those who have been intimately associated with this problem for many years, may be growing just a little weary of hearing the same old arguments repeated again and again.

It may never be possible to settle satisfactorily the question of when man made his first appearance in America, nor to point out the region from which he came, but this does not dampen the ardor of the new crop of investigators who are concerned today with producing the answers to these questions. However, in spite of the activity of recent years in the studies of American prehistory, not much has been added to our stock of knowledge upon the subject. The old, rather generally accepted, theories still hold their place pretty well and speculative interpretation is as great as ever. Lack of evidence continues to make one man's guess about as good as another's, and some of the speculation concerning the problem has been repeated so frequently that it is difficult to separate it from fact.

Therefore, starting with this admission, let us consider the theory that man came to America from Asia, and was a Mongoloid; that he came by way of Bering Strait, after the ice sheet melted sufficiently to allow him to pass into our Great Plains region. Let us continue with the theory that he was a narrow-headed type, with somewhat Australoid characteristics, that he was a hunter and food-gatherer, and without the bow, pottery, agriculture or domesticated animals, except, perhaps the dog. Some such ideas seem to be generally regarded as being near the truth.

But, let us ask: could man have come to America from somewhere else than northeastern Siberia at this early time? What about a trans-Pacific migration from Polynesia, or a trans-Atlantic migration by way of the arctic islands, or by land-bridge from Africa?

If he came by Bering Strait did he come by water and follow the coast to more hospitable latitudes, or did he cross on a land-bridge, or on the ice, or in boats across the narrowest point of the Strait and then follow the Yukon and other rivers into our Great Plains?

Did he come after the ice-sheet had melted, during the ice advance, or before the ice-sheet had formed? Did the ice leave an open corridor into the Great Plains, or was it continuous, so that man's path was blocked, and what was the situation on the Siberian side?

The answers to these questions are important, but we must admit that they cannot all be answered by marshalling facts to back them up. The truth of the matter is we cannot bring forth proof to show that man did not reach our shores by boat from the Pacific Islands. Attempts have been made to show that this was his route by comparison of certain culture traits found among some South American and Northwest Coast tribes with those of Polynesia or Melanesia or Southeastern Asia. All that can be said of the matter, in brief, is that a few boat-loads probably did reach our shores, but that it was probably in fairly recent times, since Polynesia is known not to have been inhabited at an early time. Such

as did reach American shores were probably killed by native tribes or they became absorbed by the people encountered upon their arrival. Independent invention is invoked to explain similarities in culture traits.

As for a land bridge from Africa, this is based on the fact that there is evidence for such a connection, but this, according to geologists, places the time much earlier than man is known to have existed on any Continent. There may have been an archæpelago during the early Tertiary, but there is no evidence of a direct land connection since much more ancient times. Similarities in certain phases of architecture and art between Egypt or India, and Central America could not be traced to such a land-connection, if geologists and zoölogists are correct.

There is still the North Atlantic, sub-Arctic, route from Scotland, or Norway, or Nova Zembla, by way of intervening islands. We cannot prove that man did not reach the New World by this route—nor can we prove that he did. It would have to be assumed, however, for the present, that, if he came in late Palæolithic times, he knew how to make boats suitable for voyages over open stretches of sea (if the sea was open at that time in that northern region and not covered by an ice cap). Such open stretches of sea would involve a number of open-water voyages of two to three hundred miles each.

We keep coming back to Bering Strait as being the most likely route of ingress of the first migrants to America—it involves only a short stretch of open water, with the Diomede Islands, or further south, St. Lawrence Island, on the way, so that if boats had to be used, the trip could be easily negotiated. If the ice were used as a bridge no more trouble would have been encountered than arctic peoples are faced with today in moving about in such an environment. If migrations took place during the last advance of the ice, and it should be recalled that there is evidence that the Yukon, as well as the Anadyr and other river valleys on the Siberian side, were unglaciated, then Bering Strait may have been as

open in summer as it is today. Here, however, the picture becomes complicated by the introduction of geological factors, involving changes of sea level. due to the ice sheet. During the climax, sea-level at the Strait might well have been lowered sufficiently to have caused the formation of a land-connection. Depth of the Strait is today only about thirty fathoms, and sea-level is estimated to have been, at least this much, and up to three hundred feet lower at that time. One is confronted with a good many "ifs" in the problem.

The complex nature of the Pleistocene Period in North America with its major and minor advances and retreats of the ice makes correlation difficult. Up to this point our speculations have been confined to the consideration that man arrived in the New World after the melting of the retreat of the Wisconsin ice sheet, or, at the earliest, during the Late Glacial phase. But there are those who believe that this does not leave enough time to account for the diversification of language, physical types and cultural differences, found from Alaska to the tip of South America. Since nobody knows how long, under the particular circumstances involved, it took to bring about all this differentiation, good arguments can be offered on both sides of the case. For example, an authority on glacial times, Dr. Albrecht Penck, in the *Proceedings of the International Congress of Americanists* for 1928, asks whether twenty-five thousand years is enough to account for the extensive physical and ethnological acclimatization and differentiation respectively that is to be found in the Western Hemisphere, and he points out that from six to eight adaptations to his environment would have been necessary in the geographical areas where man has accomplished such adaptations between Alaska and Tierra del Fuego. Dr. Penck questions whether such adaptation could be effected in each climatic region in an average of from three thousand five hundred to four thousand years, and therefore holds twenty-five thousand years as not sufficient for acclimatizations from the Arctic, first in a forest zone, then steppes, then desert, tropical rain forests, the high lands of the tropics, the steppes

and deserts of South America, and finally the wet cool south, not to mention a further acclimatization to the Arctic in Asia in the first place. It is, he further points out, hard to believe that a stream of humanity directed itself against the movement of the "climatic-gridle" following the retreat of the ice, and that, if such migration occurred since the last glaciation one must reckon with the passage across Bering Strait, and explain why man who crossed at that point, then undertook a migration counter to natural circumstances, which favored a migration towards the North on the Asiatic side in the first place. Penck thus finds it easier to believe that man appeared in North America as the ice began to advance, at the end of the last Interglacial stage, and that he moved south with the environment as it was changed by the ice advance.

The first question that arises to mar this picture is that which physical anthropologists would raise, namely, if man were here in an interglacial stage, why do none of the reputed early skeletal remains, so far discovered in the Americas, show more primitive characteristics, which should be the case if the corresponding human remains of Europe are used for comparison? Moreover, it would be asked could man have existed for so long a time in the New World without showing greater physical differences than are evident between our recent Indians and the remains of some of our supposedly ancient types—Lagoa Santa, Punin, Vero, Nebraska Loess Man, Minnesota Woman, and "Homo novus mundus," to mention only a few? All of which does not prove that a definitely early type will not some day be found or recognized here, for, referring again to Europe, it took a long time to find the first primitive type there, and that in an area only a fraction of the total area of North America.

At the other extreme we have Dr. Spinden's viewpoint which allows only four thousand years for the Indian's residence in the New World, and for his independent development of civilizations. Thus it is impossible to reconcile all the various viewpoints and factors involved in the problem.

No matter whether our earliest migrants were hunters who followed the larger mammals into the Plains or whether they were fishermen who followed the Coast, and later struck across into the Plains to take up hunting; and no matter whether the time was ten thousand years ago or twenty thousand years ago, we do have some facts to prove that they were here before the time of the so-called Basket Makers of our Southwest, who up to about ten years ago, were considered to be our earliest inhabitants. Kidder put a tentative date of 1500 B.C. to 2000 B.C. for their appearance, but this period has been somewhat shortened of late years.

A number of localities in the West and the Southwest have yielded evidence in recent years that leaves little doubt that man lived contemporaneously with a number of animals that are now extinct such as the ground-sloth, elephant, and an earlier bison, and whose extinction is somehow tied up with major dislocations of climate, and not with minor fluctuations that have occurred in the last seven or eight thousand years.

The first and most important discovery of this kind was that near Folsom, New Mexico, in which members of the Colorado Museum of Natural History, the American Museum of Natural History, and the Smithsonian Institution participated. Everyone is more or less familiar with this discovery. Since then there have been other finds which corroborate the evidence that man lived in North America at a time that antedated the so-called Basket Makers by several thousand years. At Conkling Cave, New Mexico, human bones with those of camels, horses and ground-sloths, among others, lay at great depth beneath a cemented layer of sand that sealed [illegible] deposits. At Gypsum Cave, Nevada, [illegible] occurred in association with remains of the ground-sloth [illegible]. At Burnet Cave, New Mexico, [illegible] people probably related to the Basket Makers, were lens-shaped deposits of charcoal and ashes [illegible] musk-ox-like ruminant in [illegible] above.

Besides these and other cave records there are those from nearly a score of open sites, located in Texas, New Mexico, Colorado, Nebraska, Minnesota and California, where the evidence of contemporaneity is conclusive or at least strongly affirmative. To mention only two, Dr. F. H. H. Roberts, Jr., working near Fort Collins, Colorado, discovered bones of extinct bison in association with a Folsom complex. Near Clovis, New Mexico, following up earlier finds by A. W. Anderson, the present writer encountered extinct bison bones, hearths with charcoal and burned bones, and, directly associated in several instances, flake knives, points and end-scrapers. At higher levels were found elephant remains.

Archæology, and Geology in its broader aspects, have thus combined in attacking the problem. Though Folsom man himself has not yet been found, and though no absolute date can be fixed for his arrival on the scene, there seems to be increasing agreement that the beautifully flaked tools that he made belong to a time, at least as early as the transition between the late glacial and early post-glacial.

In conclusion I should like to add that, through the generous support of the American Philosophical Society, it was possible to make a trip last summer to Leningrad for the purpose of studying the collections from Siberia in the Museums there. Nothing was found in any of these collections, nor had any of the scientists, of whom I inquired, ever seen anything, comparable to our Folsom points. We are, therefore, led to assume that this type of spearpoint and the technique involved in making it, represent, so far as is known at present, an American development.

University Museum,
W. Phila.

THE HEART RATE OF THE ELEPHANT

FRANCIS G. BENEDICT AND ROBERT C. LEE

(*Read April 23, 1936*)

Abstract

With an electric method employing radio amplification for transmittal of the action currents of the heart to a sensitive Moll galvanometer and special electrodes, records were obtained of the heart rates of 37 adult, female, Indian elephants, the largest weighing 8,000 and 9,000 pounds. When the elephants were standing quietly under ordinary conditions of feeding, the rates averaged 30 beats per minute. The lowest rate was 22 and the highest, 39 beats. This latter was found with the only elephant that presented any disciplinary problem and is explained by her extreme nervousness. When the elephants were lying, the rates were higher, occasionally only one or two beats higher, but usually from 8 to 10 beats higher. This is contrary to the findings with all other animals, which have lower heart rates when lying. In general, the smallest animals have the highest heart rates. The canary has been reported to have a rate of 1,000 beats, and the large domestic animals show rates of 40 or 50 beats. The elephant, with a rate of about 30 beats, fits perfectly into the picture, being the largest animal and having the lowest heart rate of any of the animals thus far studied.

Perhaps no one animal is of more general interest in comparative physiology than the elephant. Small laboratory animals have been extensively surveyed and a few of the larger domestic animals, although much study of these latter is still needed. With the elephant, however, very few physiological observations have been recorded. The elephant is anatomically a highly special form, inasmuch as it is the largest terrestrial mammal and at the same time has no protective covering of fur. In an investigation on the physiology of the elephant, including an elaborate study of one 4,000-kg. female and supplementary observations on sixty-two other females, the Nutrition Laboratory gave special attention to the heart rate measured under ordinary conditions of feeding.[1] The literature contains little information regarding the heart rate of the elephant. In the most

[1] The details of this investigation are soon to be published in monograph form by the Carnegie Institution of Washington (Publication No. 474, "The Physiology of the Elephant," by Francis G. Benedict).

authoritative book by Evans,[1] the rate is given as between 46 and 50 beats per minute. Forbes[2] obtained an electrocardiogram of an elephant from which he calculated that the heart rate (based upon the times for nine successive beats) was, on the average, 41 per minute. Occasionally hazy records in the literature, wholly uninformative as to the technique, indicate the possibility of a rate of 24 or 28 beats per minute.[3] Thus the data already available are by no means conclusive.

Technically, from the very nature of this large animal, measurements of the heart rate have been practically precluded. Anyone who has placed a stethoscope at different positions on the chest of the elephant knows that it is impossible to hear the heart sounds by this means. Legend has it that an artery sufficiently near the surface to be palpated can be found back of the ear. We have never been able to locate it. The only method that seemed sufficiently accurate and certain to make the effort worth while was that used by Alexander Forbes, namely, the electrocardiogram. As we were not interested at the time of our measurements in the character of the wave but only in the heart rate per minute, it was unnecessary to secure photographic records. Using a suitable instrument, the major impulses of each heart beat were counted directly. By means of a 4-stage radio amplification the action currents of the heart were transmitted to a highly sensitive, aperiodic galvanometer—the Moll galvanometer—and the major deflections were easily counted. For electrodes coarse wire gauze placed on rubber mats about 35 cm. square, with six or seven layers of cheese-cloth between the gauze and the mat, served the purpose admirably. The cheese-cloth was drenched with an ordinary salt solution. The elephant was ordered to stand with each of its front feet on one of these electrodes, and the connection was made instantly with the galvanometer. When care was taken to

[1] Evans, G. H., *Elephants and their Diseases*, Rangoon, 1901 and 1910.

[2] Forbes, A., Cobb, S., and McK. Cattell, *Am. Journ. Physiol.*, 1921, 55, p. 385.

[3] Colin, G., *Traité de Physiologie Comparée des Animaux*, Paris, 1888, 3d ed., 2, p. 476; Putter, A., *Arch. f. d. ges. Physiol.*, 1918, 172, tables 2 and 3, p. 379.

avoid any agitation or excitement of the elephant (and only a small amount of patience was necessary to induce these most intelligent and cooperative animals to do whatever was wanted), the heart impulses were counted without difficulty.

The first measurements were made on a docile, young female, Betsy, belonging to Mr. John T. Benson of Nashua, New Hampshire. With the coöperation of the intelligent keeper, Mr. Carl Neuffer, records of the heart rate of this animal were recorded as frequently as desired. A number of measurements showed that the heart rate was singularly uniform at about 28 beats per minute, when the elephant was standing quietly. She was then made to lie down, but the concrete floor of the barn was cold, she was uncomfortable, and it was not desirable to submit her to this cold too long. Under these conditions the large electrodes were replaced by small brass gauze electrodes having cheese-cloth between them. These were held by the keeper, wearing rubber gloves, against the soles of the two front feet. A single record indicated a heart rate of 36 beats, with the animal in the lying position. The elephant was next exercised vigorously outdoors in the ring for six minutes. Within two minutes after this exercise the heart rate, in the standing position, was 37 beats per minute. In eight minutes it had decreased to 34, and one hour after the exercise it was down to a level of 28 beats.

Another elephant studied at the Boston Zoölogical Garden was found to have an average heart rate, while standing, of about 26 beats per minute. The equipment was then transported to Campgaw, New Jersey, where the large elephant Jap, on which most of our metabolism measurements had been made, was quartered. Although the conditions there for the heart rate study were by no means so satisfactory as in the preceding series, owing to the fact that this elephant was standing on the ground, the weather was damp, and there were many stray electric currents about the place, nevertheless the records obtained led to the conviction that her heart rate while standing quietly, under ordinary conditions of feeding, was not far from 31 beats per minute.

All these observations thus far indicated a much lower rate than those reported by Evans and Forbes. The equipment was then taken to Sarasota, Florida, where (thanks to the coöperation of Mr. Edward Doherty, who at that time was in charge of the Ringling Brothers' herd) 34 female elephants were studied. The average minimum heart rates of the majority of these elephants, while standing, were 30 beats per minute or below. With two elephants there were sufficient data to establish that absolutely the lowest average minimum rate was 22 or 23 beats per minute. The highest average minimum rate with any elephant was 39 beats. This was found with the only animal that presented any disciplinary problem, and it is possible that the high rate was in large part accounted for by extreme nervousness. A few observations, typical of all those made on these elephants in the standing position, are recorded in table 1. Although the ages of these animals were not known with certainty, there was a tendency for the older elephants to have lower heart rates than the younger ones.

TABLE 1

HEART RATES OF ELEPHANTS WHILE STANDING

Elephant No.	Date	Time	Rate per Minute	Average Minimum Rate
	1935			
15	Nov. 17	10.45 A.M.	27, 30, 29, 24, 29, 30, 30, 30, 29	29
20	Nov. 18	1.28 P.M.	29, 29, 26, 26, 26, 26, 26, 26	26
23	Nov. 18	1.38 P.M.	47, 46, 40, 46, 44, 43, 42, 38, 38	39
28	Nov. 17	11.58 A.M.	28, 28, 33, 34, 34, 33, 33, 33, 33	28
30	Nov. 17	4.01 P.M.	46, 43, 40, 31, 31, 39, 33, 33	30
33	Nov. 17	1.20 P.M.	29, 23, 22, 23, 23, 23, 22, 23, 24, 24, 23	23
36	Nov. 18	12.39 P.M.	24, 22, 22, 22	22
45	Nov. 17	12.56 P.M.	41, 40, 34, 33, 33, 30, 32, 29, 30, 31, 30, 30, 29, 32, 31	30

Because of the one observation on Benson's elephant, suggesting a higher heart rate in the lying position than in the standing position, it was considered necessary to study as many of the Ringling elephants as possible while lying.

Rarely does one see an elephant asleep. It was our good fortune to obtain measurements on eighteen of these elephants during the night while they were lying, either asleep or in a condition approximating sleep. The rates when they were lying were invariably higher than those obtained in the standing position, as is shown by a typical fraction of the results reported in table 2. In a few cases the standing values were only one or two beats higher per minute but usually were from 8 to 10 beats higher. This higher heart rate in the lying position needs further investigation. Certainly, based upon this preliminary survey and with the use of the modern, easily portable electrocardiographic outfits, those interested in cardiology should find further studies on the heart rate of the elephant of value.

TABLE 2

HEART RATES OF ELEPHANTS WHILE LYING

Elephant No.	Date	Time	Rate per Minute, Lying	Average Minimum Rate, Standing
	1935			
19	Nov. 18	10.22 P.M.	32, 32, 33	27
20	Nov. 20	4.00 A.M.	31, 35	26
34	Nov. 20	1.47 A.M.	36, 39, (36)?	31
35	Nov. 18	10.28 P.M.	38, 36, 36, 36, 36	28
40	Nov. 20	1.56 A.M.	36, 39, 38	30
44	Nov. 20	1.37 A.M.	40, 40, 38	27
45	Nov. 20	2.50 A.M.	42, 43, 44, 44	30
46	Nov. 20	1.30 A.M.	32, 32, 34, 33	25

Data enabling comparisons of the heart rates of other mammals in the standing and the lying positions are not available, so far as we know, except in the case of the cow. Through the kindness of Professor E. G. Ritzman of the University of New Hampshire, a number of observations were made on cows in these two body positions, care being taken not to make the measurements until some minutes after the cow had assumed either position. These observations proved that the cow has a higher heart rate when standing than when lying.

Although it is by no means proved that there is a correlation between the heart rate of a given animal of a given species and its basal metabolism, it is established that in general the metabolism of any animal is somewhat higher when it is standing than when it is lying. In the case of the domestic animals and humans the metabolism is approximately 15 per cent higher in the standing than in the lying position. Unfortunately the metabolism of the elephant while lying has not been measured, but it is an extraordinary fact that of all the animals thus far studied the elephant is the only one that has been found to have a heart rate higher when lying than when standing. This fact is certainly challenging and should be a strong stimulus for further experiments. Circus elephants are most easily handled, they are coöperative, their trainers are highly skilled men thoroughly *en rapport* with the animals, and one can speak only in the warmest terms of appreciation of the coöperation given by the proprietors and trainers of the three herds with which we were privileged to work, namely, the Ringling Brothers' herd, the Al G. Barnes herd, and the Downie herd. For the most part little success can be obtained by working with zoölogical park elephants, but as these larger circus herds, when on tour, remain for days, if not weeks, in or near our large research centers, scientists interested in heart rate studies should certainly find ample opportunity for most illuminating investigations.

In general the smallest animals have the highest heart rates, although it is difficult to obtain accurate figures with very small animals such as rats, owing to their excitability. Nevertheless a rate of 200 beats per minute or even higher is not beyond the realm of possibility for the rat. Indeed, Miss Buchanan [1] has recorded with a capillary electrometer a rate as high as 1,000 beats per minute with the canary. The large domestic animals that have been studied show heart rates somewhat lower than do humans, averaging not far

[1] Buchanan, F., *Trans. Oxford Univ. Junior Scientific Club*, 1909, N.S., No. 34, p. 351; *Science Progress*, 1910, No. 17, p. 60; *Smithsonian Report*, 1910, p. 487.

from 40 to 50 beats. The elephant, then, with an average heart rate of about 30 beats fits perfectly into the picture so far as size is concerned, being the largest animal and having the lowest heart rate of any of the animals thus far studied. Indeed, this rate of 30 beats for the elephant while standing quietly (with one elephant a rate of 22 beats was definitely and repeatedly recorded) is notably lower than the rates of any other animals with which we have come in contact.

Nutrition Laboratory of the Carnegie Institution of Washington,
Boston, Massachusetts.

MAGNETIC FORMULÆ EXPRESSED IN THE M.K.S. SYSTEM OF UNITS

A. E. KENNELLY

(*Read by title April 25, 1936*)

ABSTRACT

Electrical engineering literature employs the practical ohm-volt-ampere series of electromagnetic units so extensively that it might be often supposed to have been written in connection with the Giorgi M.K.S. system of units. The adoption of the Giorgi System by the International Electrotechnical Commission in June, 1935, therefore, introduces no change in the current literature of the voltaic circuit or of the continuous current electrical engineering circuit. Owing, however, to the action of the International Electrical Congress of Chicago in 1893, it is an almost universal custom to employ the C.G.S. magnetic system of units in the literature of the magnetic circuit for engineers. The following paper presents a number of electrotechnical formulæ for the magnetic circuit in M.K.S. units, together with arithmetical examples of their use, in the hope of aiding students to apply the M.K.S. System in magnetic-circuit computations. A number of these formulæ are independent of the question of "rationalisation." The formulæ which are affected by "rationalisation" are presented in both rationalised and unrationalised, or classical, form in parallel columns, so that the reader may choose between these two forms.

Purpose and Scope

LONG PRIOR to the international adoption of the Giorgi M.K.S. system of units, the literature of electrical engineering was largely Giorgian, in the sense that the practical series of nine international electromagnetic units was so extensively used, it would often be difficult to decide whether the authors of papers were using the system or merely the series. There has, however, been for many years one field of applied science: *i.e.* magnetics, in which—owing to the actions of International Electrical Congresses at Chicago, in 1893, and at Paris, in 1900—the units employed were almost entirely confined to the classical C.G.S. magnetic system of Maxwell. It is proposed here to present a considerable number of the working formulæ of applied magnetics and electromagnetics in the Giorgi system, together with arithmetical examples of their use. It is also proposed to do this without introducing the classical concept of isolated magnetic point-poles. That

concept was of great value and service in the days before the development of the theory of magnetic circuits and of the electromagnetic field; but it has become artificial, and unrealisable experimentally, in view of the scientific accomplishments of the last forty years.

Induced Electromotive Force

Although by no means the first in historical sequence, one of the most fundamental laws of electromagnetics is that giving the e.m.f. generated in a conductor moving across a uniform magnetic field. In the simplest case, a thin straight wire of length l *meters* moves with uniform velocity v *meters per second* perpendicularly across a uniform magnetic field of flux density B *webers per* m^2. During the motion, the e.m.f. generated in the wire obeys the formula:

$$e = Blv \qquad \textit{volts} \tag{1}$$

and its direction is given by the "right-hand rule." [1]

A formula in magnetics may be described as *independent*, when the units entering it are independent of, or unaffected by, the question of rationalisation. On the other hand, formulæ that are affected by the question of rationalised vs. unrationalised units, may be called *dependent* formulæ. Formula (1) above is independent, because none of the units it employs is affected by the question of rationalisation. Dependent formulæ will be presented in both rationalised and unrationalised (or classical) units, so that the reader may follow either method of notation and computation. The Giorgi system admits of being used with either rationalised or classical units, and since there is much difference of opinion over the question, each reader and writer should be free to follow his own choice in the matter.

Example (I). The axle of a pair of wheels on a train is moving at a uniform speed of 100 *km. per hr.* horizontally, in

[1] If the right-hand thu*m*b, *f*ore-finger and m*i*ddle finger are held so as to represent three coordinate axes: then, if the conductor be *m*oved in the direction of the thu*m*b, across a *f*ield directed along the *f*ore-finger, the m*i*ddle finger will indicate the direction of the *i*nduced e.m.f. Positive electricity in the conductor tends to move in this direction.

open country, where the vertical component of the earth's magnetic field is 0.3 *gauss*, or 0.3×10^{-4} *weber m.*^{2}, directed downward (the north-seeking pole of a suspended compass needle dipping). The length of the axle, considered as a moving conductor, is taken as 56.5 *inches* (1.435 *m.*), and the earth's local magnetic field is supposed to be unaffected by the steel in the car structure. Find the e.m.f. induced in the axle.

Here $l = 1.435$ *meters*, $B = 0.3 \times 10^{-4}$ *weber/m.*^{2}, and $v = 27.78$ *m./sec.* Hence $e = 0.3 \times 10^{-4} \times 1.435 \times 2.778 \times 10 = 1.196 \times 10^{-3}$ *volt*. By the "right-hand rule,"[1] this e.m.f. will be directed towards the left.

Example (II). A vertical insulated antenna, 50 *feet* (15.24 *m.*) high, and grounded perfectly at its base, stands in the path of a plane polarised northwardly-moving radio wave, in which the instantaneous horizontal flux density B is 10^{-8} *gauss* (10^{-12} *weber/m.*^{2}) directed westward. The wave is moving past the antenna, parallel to the perfectly conducting ground surface, at the light speed (3×10^8 *m./sec.*). What is the instantaneous e.m.f. induced in the antenna, and the electric intensity or voltage gradient?

Here $e = 10^{-12} \times 1.524 \times 10 \times 3 \times 10^8 = 4.572 \times 10^{-3}$ *volt*. The electric intensity in *volts per meter* is $Bv = 10^{-12} \times 3 \times 10^8 = 3 \times 10^{-4}$ *volt/m.* The direction of the instantaneous e.m.f. in the antenna will be the same as though the westward flux density were at rest, and the antenna were moved across it at the light speed southward. By the "right-hand rule," the e.m.f. would then be downward.

Generation of E.M.F. in a Conducting Loop (Independent)

If a plane loop of wire moves relatively to a magnetic flux Φ, so that the amount of flux linked with the loop undergoes change, it is known that an e.m.f. will be induced in the loop during the change, and will cease when the change ceases.

If the loop lies, say, in the horizontal plane, and flux enters it at the uniform rate of Φ *webers* during T *seconds*, the e.m.f. induced in the loop will be steady during that time, at

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If the loop lies, say, in the horizontal plane, and flux enters it at the uniform rate of Φ *webers* during T *seconds*, the e.m.f. induced in the loop will be steady during that time, at

$E = -\Phi/T$ *volts; i.e.*, the voltage induced in the wire loop will be equal to the rate of change of flux linking when expressed in *webers per sec.* If the flux enters the loop upward, as when a north-seeking magnetic pole is brought up to the loop from below, the e.m.f. in the loop will be in a clockwise or negative direction around the loop. The equation therefore takes the negative sign. The clockwise or negative e.m.f. would tend to set up a corresponding clockwise current around the loop, as viewed from above. By Lenz's law, this current would tend to set up a magnetic flux through the loop in a downward direction, or *opposed* to the generating entering flux.

If the inducing flux Φ does not enter uniformly with time, the instantaneous e.m.f. induced in the loop will be:

$$e = -\,\mathrm{d}\Phi/\mathrm{d}t \qquad \textit{volts.} \qquad (2)$$

During irregular linking, the value of the induced e.m.f. may vary widely, but it will be evident that for a given total amount of flux Φ_t introduced into the loop during a total time interval T seconds, the time integral of induced e.m.f. will be

$$\int_0^T e\cdot\mathrm{d}t = -\,\Phi_t \qquad \textit{webers} \text{ or } \textit{volt-seconds} \qquad (3)$$

and this will have the same value, however irregularly the linkage takes place.

If a coil of insulated wire has N turns in series, and a flux Φ is permitted to link with all of them simultaneously, each turn will possess an induced e.m.f. of $-\,\mathrm{d}\Phi/\mathrm{d}t$ *volts;* so that the total induced e.m.f. will be

$$e = -\,N\mathrm{d}\Phi/\mathrm{d}t \qquad \textit{volts.} \qquad (4)$$

Alternating E.M.F. Induced in a Coil by a Simple Alternating Flux (Independent)

If a coil of N turns is linked with a simple alternating flux of the type $\Phi_m \sin \omega t$ *webers: i.e.*, a sinusoidal flux of angular velocity $\omega = 2\pi f$ *radians/second*, where f is the frequency of

alternation in *cycles/second;* the *instantaneous* e.m.f. induced in the coil will be:

$$e = -N\mathrm{d}(\Phi_m \sin \omega t)/\mathrm{d}t = -N\Phi_m\omega \cos \omega t \qquad \textit{volts}, \quad (5)$$

of which the maximum cyclic value will be

$$E_m = \Phi_m N\omega = 2\pi f N\Phi_m \qquad \textit{volts}. \quad (6)$$

The effective or root-mean-square value of this voltage, as shown by a properly calibrated voltmeter, will be

$$E = E_m/\sqrt{2} = 4.442 f N\Phi_m \qquad \textit{volts}. \quad (7)$$

Example (III). If the secondary winding of a single-phase a.c. transformer has 600 turns, through each and all of which passes a maximum cyclic sinusoidal flux Φ_m of 2.5×10^{-2} *weber*, at a frequency f of 60 ~ ($\omega = 377$ *rad./sec.*), what is the e.m.f. induced in the winding?

By (6), $E_m = \Phi_m N\omega = 2.5 \times 10^{-2} \times 6 \times 10^2 \times 3.77 \times 10^2$
$= 5.655 \times 10^3$ *max. cy. volts,*
and $E = E_m/\sqrt{2} = 3.998 \times 10^3$ *effective volts.*

E.M.F. Developed in a D.C. Bipolar Generator Armature (Independent)

If a direct-current bipolar generator has N surface wires counted once around the armature; also if the speed of armature rotation be n *revolutions per second;* then if each field-pole delivers Φ *webers* usefully into the armature, it can be shown by (4) that the e.m.f. delivered at the brushes will be:

$$E = \Phi N n \qquad \textit{volts}. \quad (8)$$

If the generator is multipolar. the same rule holds; except when the armature is "series-wound," with a single pair of brushes. In that case, the e.m.f. generated will be:

$$E = p\Phi N n \qquad \textit{volts}, \quad (9)$$

where p is the number of pairs of poles.

Example (IV). If a quadripolar, 4-brush, d.c. generator runs at 300 *revs. per min.* ($n = 5.0$ *r.p.s.*) and has 200 wires embedded in the surface of the armature, and each field pole delivers 0.55 *weber* usefully to the armature, so that each conductor in passing one pole cuts 0.55 *weber*, find the internally generated e.m.f.

By (8), $E = 0.55 \times 2 \times 10^2 \times 5 = 5.5 \times 10^2 = 550$ *volts*.

Under load, the e.m.f. at the brushes may be expected to fall somewhat below this value, if only on account of potential drop in armature and brush resistance.

Magnetomechanical Forces on Active Straight Conductors (Independent)

If a straight conductor, of length l *meters*, lies perpendicularly across a uniform flux density, B *webers/m.*[2], and carries a continuous current, I *amperes*, the force exerted by the field upon the conductor will be:

$$F = BlI \qquad \textit{joules/m.}^{1} \qquad (10)$$

The direction of this force F is perpendicular both to the flux and to the current, and is indicated by the "left-hand rule."[2]

Example (V). A straight horizontal east-west wire, 0.5 *m.* long, is supported in the earth's magnetic field, where $B = 0.25$ *gauss* (0.25×10^{-4} *weber m.*[2]), directed north and dipping 60° downward. A current of 40 *amperes* passes steadily through the wire eastward. Find the strength and direction of the mechanical force thereby exerted on the wire.

By (10), $F = 0.25 \times 10^{-4} \times 0.5 \times 4 \times 10$
$= 0.5 \times 10^{-3}$ *joule/m.*
$= 50$ *dynes*.

By the "left-hand rule," this force will be directed north, and at an angle of 30° above the horizontal plane.

[1] A *joule per meter* is equal to 10^5 *dynes*, and is approximately the weight of 102 *grams*.

[2] If the left-hand *fore-finger* points in the direction of the *flux*, the second finger in the direction of the *current*, the thumb will be in the direction of the *magnetomechanical force*, the three directions being taken as mutually perpendicular.

Magnetic Potential Distribution Around a Straight Active Conductor Due to the Current it Carries (Dependent)

Rationalised	*Unrationalised*
A current of I *amperes* in the wire establishes a m.m.f. $\mathfrak{F}$ or M of I *ampere-turns*, or $M = I$ *amp.-turns* * (11) around the wire.	A current of I *amperes* in the wire establishes a m.m.f. $\mathfrak{F}$ or M of $4\pi I$ M.K.S. nonrationalised units, or $M = 4\pi I$ :::† (11) around the wire.

The magnetic potential is the same, for one encirclement of the wire, in any radial plane passing through the axis of the wire. The potential distribution is therefore a distribution of radial planes emerging from the axis. There will be I unit planes in the rationalised picture, and $4\pi I$ unit planes in the classical picture.

Magnetic Flux Distribution Around a Long Straight Active Conductor

Since the equipotential magnetic surfaces form a system of radial planes through the axis of the conductor, and the magnetic flux is always perpendicular to the local equipotential surface, it follows that the distribution of magnetic flux surrounding a straight active wire is a system of coaxial cylinders, with the wire at the center. In any plane perpendicular to the wire, the flux paths are concentric circles, extending indefinitely outwards. At radius r *meters* from the axis of the wire, the length of the flux path is $2\pi r$ *meters*. The m.m.f. $\mathfrak{F}$ or M active in each and all of these flux paths, due to the current in the wire, is the same; namely I *amp.-turns* in rationalised, and $4\pi I$ units in unrationalised measure.

* The "turn" in the *ampere-turn* around a straight conductor may be assigned to the return conductor, somewhere needed for completing the electric circuit for the current.

† No name has yet been assigned internationally to the practical classical unit of m.m.f. It had been proposed to call it the "*pragilbert*," with a magnitude of one tenth of a *gilbert* in the classical C.G.S. system. The prefix "pra" did not, however, meet with international favor in the I.E.C. The name will here be left blank. Anonymous units will be indicated by the symbol :::.

Gradient of Potential, or Magnetic Intensity H Around Wire (Dependent)

The magnetic intensity H, or gradient of magnetic potential, at any distance r *meters* from the wire's axis, will be distributed uniformly around the circle, of circumference $2\pi r$ *meters*, followed by the flux at that radius. Thus:

Rationalised	*Unrationalised*
$H = I/2\pi r$ *amp.-turns/m.* (12)	$H' = 4\pi I/2\pi r = 2I/r$ *unrat. units m.m.f./m.* (12)

Example (VI). A long straight wire carries a steady current of 100 *amperes*. What is the magnetising force, magnetic intensity or gradient of magnetic potential H around the wire at a radial distance of 50 *cm.*?

Rationalised	*Unrationalised*
$H = 100/(2\pi \times 0.5) = 100/\pi = 31.83$ *amp.-turns/m.*	$H' = 200/0.5 = 400$ *unrat. units m.m.f./m.*

Magnetic Flux Density B Surrounding a Straight Wire[1] *in Nonmagnetic Medium, Due to the Current it Carries (Independent)*

$$B = \mu_0 H \qquad \textit{webers/m.}^2, \qquad (13)$$

where μ_0 is the space permeability; *i.e.*, the permeability of vacuum or free space or nonmagnetic material.

Space Permeability μ_0 (Dependent)

Although formula (13) is symbolically independent of rationalisation, yet its arithmetical reduction is dependent, since the numerical value of μ_0 is affected by rationality.

[1] The direction of the magnetic flux density B around an active wire is to the steady current it carries, as is the rotation of an ordinary right handed screw to the advance or retreat of the same. Thus an observer looking along a wire in which the current is flowing away from him might visualise the magnetic flux as being directed clockwise around the wire from his viewpoint.

Rationalised	*Unrationalised*
$\mu_0 = 4\pi \times 10^{-7} = 1.257 \times 10^{-6}$ *henrys/m.* (14)	$\mu_0' = 10^{-7}$ ::: (14)

This constant μ_0 is a fundamental property of free space.

Example (VII). A long straight wire carries a steady current of 200 *amperes*. Find the gradient of potential H and the flux density B in the surrounding air, considered as a nonmagnetic medium at a radial distance of 20 *cm.* from the axis of the wire.

Here, in (12), $I = 200$, and $r = 0.2$ *m.*

Rationalised	*Unrationalised*
$H = 200/(2\pi \times 0.2) = 500/\pi$	$H' = 2 \times 200/0.2 = 2{,}000$
$= 159.2$ *amp.-turns/m.*	*unrat. units.*
$B = 4\pi \times 10^{-7} \times 500/\pi$	$B = 10^{-7} \times 2 \times 10^3$
$= 2 \times 10^{-4}$ *weber/m.*^{2}.	$= 2 \times 10^{-4}$ *weber/m.*^{2}.

It is evident that the flux density B, being in independent units, must have the same numerical value by either method of deduction.

Magnetomechanical Force of Attraction or Repulsion between Two Long Parallel Straight Wires in Free Space, Due to the Currents they Carry (Dependent)

If the distance between the axes of the two wires (a) and (b) is r *meters*, and the steady currents they respectively carry are I_a and I_b *amperes*, we may, for convenience, regard one wire, say (a), as fixed, and the other, (b), as free to move under the magnetomechanical force between them. Each wire's current produces its own cylindrical flux distribution; but by (10), the force exerted on any length l *meters* of (b) will be $F = B_a l I_b$ *joules/m.* The linear force on (b), or force per meter of the parallel system, will thus be $f = B_a I_b$ *joules/m.*^{2}.

This formula is symbolically independent, but its solution is dependent:

Rationalised	*Unrationalised*
$f = B_a I_b = \mu_0 H_a I_b$	$f = B_a I_b = \mu_0' H_a' I_b$
$= 4\pi \times 10^{-7}$	$= 10^{-7} \times (4\pi I_a/2\pi r)$
$\times (I_a/2\pi r) \times I_b$	$\times I_b$
$= 2 \times 10^{-7} \times I_a I_b / r$	$= 2 \times 10^{-7} \times I_a I_b / r$
joules/m.^{2}. (15)	*joules/m.*^{2}. (15)

Example (VIII). Find the linear repulsive force f between two outgoing and return parallel wires in air—air being taken as a nonmagnetic medium—each wire carrying 1 *ampere*, at an interaxial distance of 1 *meter*.

Here $r = 1$ *m.*, and $I_a = I_b = 1$; so that $f = 2 \times 10^{-7}$ *joule/m.*^{2}. This force (2×10^{-2} *dyne*) would be much too small to measure with precision; but formula (15) may be taken as defining[1] the magnitude of the *ampere*. A Kelvin or a Rayleigh Current Balance may be regarded as an instrument embodying this principle, but with the force greatly enhanced by the use of wire coils.

By means of the "left-hand rule," it can be shown that the mechanical force between two active parallel wires is always attractive when their currents are in the same direction, and repulsive when in opposite directions.

Torque Exerted on the Active Armature of a Bipolar Direct-Current Motor (Independent)

If the flux passing usefully into the armature from either field pole is Φ *webers*, N the number of conductors lying on the armature surface, and I the current in *amperes* supplied, through either brush, to the commutator, the torque exerted by the armature is:

$$\tau = \Phi N I / 2\pi \qquad \textit{joules/radian.} \qquad (16)$$

In the case of a multipolar motor, not series wound, and having as many brushes as field poles, the rule is the same, I being then the total current supplied to the armature, and Φ the useful flux supplied by each pole. The direction of the

[1] Report of the Comité Consultatif d'Electricité, Paris, Oct., 1935

torque, and therefore of the armature's tendency to rotate, follows the "left-hand rule."

Example (IX). If a quadripolar, 4-brush D.C. motor has $N = 200$ wires embedded in its armature surface, and each fieldpole delivers 0.55 *weber* usefully into the armature; then if the current delivered usefully to the armature is $I = 100$ *amperes*, find the torque produced by the current, whether the armature is clamped or running.

$$\tau = 0.55 \times 2 \times 10^2 \times 10^2/2\pi = 0.55 \times 10^4/\pi$$
$$= 1.750 \times 10^3 \qquad \textit{joules/radian.}$$

Mechanical Power of Rotating Armature (Independent)

If the armature is allowed to run freely at *n revolutions per second*, while receiving current *I amperes*, under the same excitation, the angular velocity of the armature will be

$$\omega = 2\pi n \qquad \textit{radians/sec.} \qquad (17)$$

and the mechanical power developed by the rotating armature against all opposing torques, including the load torque, will be

$$P = \tau\omega \qquad \textit{watts.} \qquad (18)$$

Example (X). In the case of the quadripolar motor considered in the last example, running steadily at 300 *r.p.m.* (5 *r.p.s.*), the angular velocity ω will be 31.42 *radians/sec.* Find the armature mechanical power developed.

Here $\tau = 1.750 \times 10^3$, and $\omega = 3.142 \times 10$.

Thus $P = 1.750 \times 10^3 \times 3.142 \times 10 = 5.5 \times 10^4$ *watts*, or 55 *kw.*

We have also seen, in Example (IV), that the armature would generate 550 *volts* at that speed and excitation. The electrical input to the armature would therefore be $P = EI = 550 \times 100 = 55{,}000$ *watts* = 55 *kw.* All armature losses would have to be deducted from this input in order to find the motor output in *watts.*

The Electromagnetic Circuit. Simple Forms

The simple electromagnetic circuit consists of a solenoid, or simple spiral insulated winding applied to a core of uniform cross-section formed of wood, porcelain, or other nonmagnetic material, taken as having the same permeability as free space. The core may have either of two simple geometrical forms: (A) An indefinitely long straight cylinder, wound with n turns of exciting wire per *meter* of length. This is called the long straight solenoid. (B) An anchor ring or toroid of uniform cross section, covered with n turns of wire per *meter* of mean circumference. This is called the closed circular solenoid. The straight solenoid is supposed to be so long that the poles produced at its ends, on excitation, are too remote to affect appreciably the distribution of magnetic flux in the core, within the region investigated.

The closed circular solenoid has theoretically no poles, and no external polarity. In order that the flux density may be taken as uniform over all parts of the core cross-section, the diameter of the toroid must be large with respect to the diameter of the nonmagnetic core. The residual error may, however, be computed by known formulæ.

The Long Straight Solenoid
Magnetising Force H (Dependent)

If an excitation current of I *amperes* is supplied to the winding, of n *turns per meter*, the magnetising force H, or magnetic intensity or linear m.m.f., will be:

Rationalised	*Unrationalised*
$H = nI$ *amp.-turns/m.* (19)	$H' = 4\pi nI$ *unrat. units m.m.f./m.* (19)

Flux Density B (Independent)

The uniform magnetic flux density B in the core will then be:

$$B = \mu_0 H \qquad \textit{webers/m.}^2. \qquad (20)$$

Substituting (14), this becomes:

$B = 4\pi \times 10^{-7} \times nI$ *webers/m.²*. (21)	$B = 10^{-7} \times 4\pi nI$ *webers/m.²*. (21)

Flux Φ *(Independent)*

If s is the cross-sectional area of the core in *m.²*, the total flux is:

$$\Phi = Bs = 4\pi nIs \times 10^{-7} \quad webers. \qquad (22)$$

Magnetisation Intensity $\mathfrak{J}$ *(Dependent)*

The magnetisation in the core will be:

$\mathfrak{J} = B$ *webers/m.²*. (23)	$\mathfrak{J}' = B/4\pi$ *unrat. units*. (23)

Example (XI). A long straight solenoid is wound with 10 *turns per linear cm.* ($n = 1000$ *turns/m.*). Its cross-sectional area is 12 *cm.²* (1.2×10^{-3} *m.²*). If the excitation current is $I = 5$ *amperes*, find H, B, Φ and $\mathfrak{J}$.

By (19), $H = 10^3 \times 5 = 5 \times 10^3$ *amp.-turns/m.*,

$H' = 4\pi \times 10^3 \times 5 = 6.283 \times 10^4$ *unrat. units m.m.f./m.*

By (21), $B = 4\pi \times 10^{-7} \times 10^3 \times 5 = 6.283 \times 10^{-3}$ *weber/m.²* $= 62.83$ *gauss*.

By (22), $\Phi = 6.283 \times 10^{-3} \times 1.2 \times 10^{-3}$
$= 7.54 \times 10^{-6}$ *weber* $= 754$ *maxwells*.

By (23), $\mathfrak{J} = 6.283 \times 10^{-3}$ *weber/m.²*,
$\mathfrak{J}' = 6.283 \times 10^{-3}/4\pi = 5 \times 10^{-4}$ *unrat. units*.

Closed Circular Solenoid with Non-Ferric (Nonmagnetic) Core

Fig. 1 represents, in plan view and in cross section, a simple toroid, or closed circular solenoid, of mean diameter D *meters*, and of core cross-section $s = h^2$ *square meters*. The core is of square cross section, and is composed of non-ferric or nonmagnetic material, taken as having the same

permeability μ_0, or reluctivity $\nu_0 = 1/\mu_0$, as free space. A winding of N turns of insulated wire is uniformly applied to this toroid.

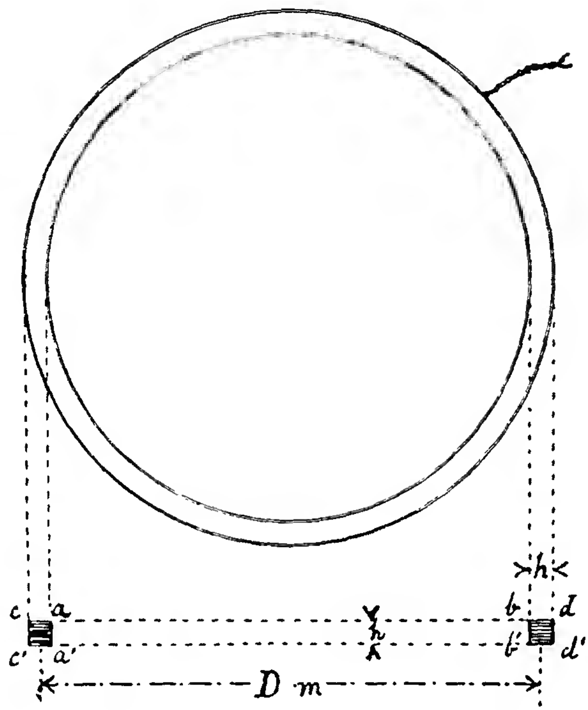

FIG. 1 Simple toroidal magnetic circuit or closed circular solenoid.

Reluctivity of Core ν_0 (Dependent)

Rationalised	*Unrationalised*
$\nu_0 = 10^7/4\pi$ $= 0.7958 \times 10^6$, or in round numbers, 0.8×10^6 *m./henry.* (24)	$\nu_0' = 10^7$ *unrat. units.* (24)

The reluctivity ν_0 of free space is a fundamental space constant.

Reluctance of Core $\mathcal{R}$ *(Dependent)*

The reluctance of a rectangular prism of free space, having a length of l *meters*, and a cross sectional area of s *m.*^{2}, is symbolically independent at

$$\mathcal{R} = \nu_0 l/s \quad \textit{amp.-turns/weber.} \qquad (25)$$

Substituting (24):

$\mathcal{R} = (10^7/4\pi) \times l/s$ *amp.-turns/weber.* (26)	$\mathcal{R}' = 10^7 \times l/s$ *unrat. units.* (26)

Permeance of Core $\mathcal{P}$ *(Dependent)*

The permeance of the core is the reciprocal of its reluctance, and is symbolically independent at

$$\mathcal{P} = \mu_0 s/l = s/\nu_0 l \qquad \textit{webers/amp.-turn} \qquad (27)$$

or by (14)

$\mathcal{P} = 1.257 \times 10^{-6} \times s/l$ *webers/amp.-turn.* (28)	$\mathcal{P}' = 10^{-7} \times s/l$ *unrat. units.* (28)

Magnetomotive Force of Winding with I Amperes Excitation (Dependent)

$\mathfrak{F}$ or $M = NI$ *amp.-turns.* (29)	$\mathfrak{F}'$ or $M' = 4\pi NI$ *unrat. units.* (29)

Magnetic Intensity H (Dependent)

$H = NI/l$ *amp.-turns/m.* (30)	$H' = 4\pi NI/l$ *unrat. units.* (30)

Magnetic Flux Φ *(Symbolically Independent)*

$$\Phi = M/\mathcal{R} = M\mathcal{P} \qquad \textit{webers.} \qquad (31)$$

$\Phi = NIs \times 4\pi \times 10^{-7}/l$ *webers.* (32)	$\Phi = 4\pi NIs \times 10^{-7}/l$ *webers.* (32)

Flux Density B (Independent)

$$B = \Phi/s \qquad \textit{webers/m.}^2. \qquad (33)$$

Example (XII). A closed nonferric circular solenoid has a mean circumference of $l = 1.5$ *meters*, and a cross-sectional area of $s = 4\ cm.^2\ (4 \times 10^{-4}\ m.^2)$. It is wound with $N = 1500$ *turns*, carrying $I = 5$ *amperes*. Find the m.m.f. of the winding, the reluctance and permeance of the core, the core flux and flux density.

$$l/s = 1.5/(4 \times 10^{-4}) = 3.75 \times 10^{3} \qquad m.^{-1}.$$

Rationalised	*Unrationalised*
$\mathfrak{F}$ or $M = 1.5 \times 10^3 \times 5$ $= 7.5 \times 10^3$ *amp.-turns.*	$\mathfrak{F}'$ or $M' = 4\pi \times 7.5 \times 10^3$ $= 9.424 \times 10^4$ *unrat. units.*
$\mathcal{R} = (10^7/4\pi) \times 3.75 \times 10^3$ $= 2.984 \times 10^9$ *amp.-turns/weber.*	$\mathcal{R}' = 10^7 \times 3.75 \times 10^3$ $= 3.75 \times 10^{10}$ *unrat. units.*
$\mathcal{P} = 1/(2.984 \times 10^9)$ $= 3.351 \times 10^{-10}$ *webers/amp.-turn.*	$\mathcal{P}' = 1/(3.75 \times 10^{10})$ $= 2.667 \times 10^{-11}$ *unrat. units.*
$\Phi = 7.5 \times 10^3/(2.984 \times 10^9)$ $= 2.513 \times 10^{-6}$ *webers.*	$\Phi = 9.424 \times 10^4/(3.75 \times 10^{10})$ $= 2.513 \times 10^{-6}$ *webers.*
$B = 2.513 \times 10^{-6}/(4 \times 10^{-4})$ $= 6.283 \times 10^{-3}$ *webers/m.²*	$B = 6.283 \times 10^{-3}$ *webers/m.²*

Magnetic Intensity H, or Gradient of Magnetic Potential (Dependent)

$H = M/l = NI/l$ *amp.-turns/m.* (34)	$H' = M'/l = 4\pi NI/l$ *unrat. units.* (34)

Magnetic Quantity m, or Displacement (Dependent)

$m = \Phi$ *webers.* (35)	$m' = \Phi/4\pi$ *unrat. units.* (35)

Surface Density m/s, or Intensity of Magnetisation of Core $\mathfrak{I}$ *(Dependent)*

$\mathfrak{I} = m/s = \Phi/s = B$ *webers/m.²* (36)	$\mathfrak{I}' = m'/s = \Phi/4\pi s$ $= B/4\pi$ *unrat. units.* (36)

Volume Energy of Core Magnetisation (Dependent)

$w = HB/2 = H^2\mu_0/2$	$w' = H'B/8\pi$
$= B^2/2\mu_0$	$= H'^2\mu_0'/8\pi$
$= B^2/(8\pi \times 10^{-7})$	$= B^2/8\pi\mu_0'$
joules/m.^{3}. (37)	$= B^2/(8\pi \times 10^{-7})$
	joules/m.^{3}. (37)

Total Energy of Core Magnetisation $W = Vw$ (Dependent)

$W = Vw = sl \times HB/2$	$W' = Vw'$
$= lH\Phi/2 = M\Phi/2$	$= sl \times H'B/8\pi$
joules. (38)	$= M'\Phi/8\pi$ *joules.* (38)

Inductance of Winding (Independent)

$$\mathfrak{L} = N\Phi/I \qquad \textit{henries.} \qquad (39)$$

Electromagnetic Energy of Winding W (Independent)

$$W = \mathfrak{L}I^2/2 \qquad \textit{joules.} \qquad (40)$$

Example (XIII). In the core of the last example, find the magnetic intensity H, the magnetic quantity m, the intensity of magnetisation $\mathfrak{J}$, the volume energy w and the total energy W; also the inductance $\mathfrak{L}$ and the electromagnetic energy W of the winding.

Rationalised	*Unrationalised*
$H = 1.5 \times 10^3 \times 5/1.5$	$H' = 4\pi \times 1.5 \times 10^3 \times 5/1.5$
$= 5 \times 10^3$ *amp.-turns/m.*	$= 6.283 \times 10^4$ *unrat. units.*
$m = \Phi = 2.513 \times 10^{-6}$ *webers.*	$m' = 2.513 \times 10^{-6}/4\pi$
	$= 2 \times 10^{-7}$ *unrat. units.*
$\mathfrak{J} = B = 6.283 \times 10^{-3}$ *webers/m.*^{2}.	$\mathfrak{J}' = 6.283 \times 10^{-3}/4\pi$
	$= 5 \times 10^{-4}$ *unrat. units.*
$w = 5 \times 10^3 \times 6.283 \times 10^{-3}/2 = 15.71$ *joules/m.*^{3}.	$w = 6.283 \times 10^4 \times 6.283 \times 10^{-3}/8\pi = 15.71$ *joules/m.*^{3}.
$W_m = 7.5 \times 10^3 \times 2.513 \times 10^{-6}/2 = 9.424 \times 10^{-3}$ *joule.*	$W_m = 9.424 \times 10^4 \times 2.513 \times 10^{-6}/8\pi = 9.424 \times 10^{-3}$ *joule.*

$\mathfrak{L} = 1.5 \times 10^3 \times 2.513 \times 10^{-6}/5 = 7.54 \times 10^{-4}$ *henry.*

$W_e = 7.54 \times 10^{-4} \times 5^2/2 = 9.424 \times 10^{-3}$ *joule.*

Closed Circular Solenoid with Ferric or Magnetic Core

When an iron core is substituted for the nonferric core, say of wood, in fig. 1, it is well known that the magnetic flux Φ in the core, for a given applied m.m.f., may be much greater than when the core is nonferric. According to an Ohm's law analogy of the magnetic circuit, this increase in flux might be attributed either to greater permeance in iron than in wood, or to an unchanged permeance in the core but to an increased m.m.f. evoked by the m.m.f. of the winding; or to a combination of both these causes. If the increase were due entirely to increased permeance, then there should be no residual flux in the core, when the m.m.f. of excitation is withdrawn. It is, however, known that on interrupting the exciting current, there may be a considerable residual flux in the core—in special cases the residual flux may be as much as 85 per cent of the flux under excitation—which shows that at least a considerable part of the additional flux in the iron core must be assigned to a structural m.m.f. in the iron evoked by the impressed m.m.f. Nevertheless, for many electrotechnical purposes it is convenient to assume that the m.m.f. in the magnetic circuit is merely that of current excitation, and that the increase of flux in the iron core is entirely due to an increase of permeance and permeability μ.

According to this convention, the total flux Φ in the core, at a given steady excitation, is divisible into two parts; namely: (*a*) a space flux Φ_0, such as would be developed in the space occupied by the core if it were nonmagnetic, and (*b*) a metallic flux or magnetic core flux Φ_m, set up in the magnetic material of the core and superposed on, or added to, the space flux. That is:

$$\Phi = \Phi_0 + \Phi_m \qquad \textit{webers.} \tag{41}$$

Beyond this point, the reasoning is dependent on the rationalisation question. No free poles are developed in the closed magnetic core; but we may assume that in magnetisation, there is a magnetic displacement, or a movement of

magnetic quantity all along the core, such as would produce a free pole strength m. In rationalised theory, a pole of strength m delivers a flux $\Phi = m$; whereas in unrationalised theory, a pole of strength m delivers a flux $\Phi = 4\pi m$. Consequently:

Rationalised	*Unrationalised*
$\Phi = \Phi_0 + m$ *webers.* (42)	$\Phi = \Phi_0 + 4\pi m'$ *webers.* (42)

Dividing by the uniform core cross-sectional area s *square meters:*

$B = B_0 + B_m$ *webers/m.*^{2}, (43)	$B = B_0 + 4\pi m'/s$ *webers/m.*^{2}, (43)

where B_0 is the space flux density for a vacuum or nonmagnetic core, and B, the total flux density of both space and magnetised core. Again:

$B = B_0 + \mathfrak{J}$ *webers/m.*^{2}. (44)	$B = B_0 + 4\pi\mathfrak{J}'$ *webers/m.*^{2}. (44)

Here $\mathfrak{J}$ is the "intensity of magnetisation" or magnetic quantity per unit of area. In rationalised terms, $\mathfrak{J} = B_m$, whereas in unrationalised terms, $\mathfrak{J}' = B_m/4\pi$. Finally, dividing throughout by the magnetising force H, or gradient of magnetic potential:

$\mu = \mu_0 + \mu_m$ *henrys/m.*, (45)	$\mu' = \mu_0' + 4\pi\kappa'$ *henrys/m.*, (45)

where μ_m is the metallic permeability of the magnetised core, and κ, in unrationalised terms, is the "magnetic susceptibility" of the material.

In unrationalised theory, the definition of susceptibility is

$$\kappa' = (\mu' - \mu_0')/4\pi \quad \therefore \quad (46)$$

It is an important characteristic of magnetic materials per unit of their volume. It is the pole strength per cubic meter of the material as elicited by a magnetising force H' in unrationalised M.K.S. units. The corresponding characteristic in rationalised theory is μ_m, the metallic permeability

for an assigned H in *ampere-turns per meter.* Here:

$$\mu_m = \mu - \mu_0 = 4\pi\kappa \quad \textit{henrys/m.} \tag{47}$$

If we divide (45) through by μ_0, the absolute permeability of space:

$$\mu/\mu_0 = 1 + \mu_m/\mu_0 \quad \textit{numeric.} \quad (48) \qquad \Big| \qquad \mu'/\mu_0' = 1 + 4\pi\kappa'/\mu_0' \quad \textit{numeric.} \quad (48)$$

Here μ/μ_0, the ratio of the total permeability to the space permeability, both in absolute measure, is the total relative permeability of the core and space. It is a numerical ratio. Similarly, μ_m/μ_0 is the numerical relative metallic permeability.

In practical applications, relative permeabilities are ordinarily large with respect to unity; so that, since μ/μ_0 and μ_m/μ_0 differ always by unity, it is unimportant to discriminate between them. The relative permeability of the core is therefore ordinarily taken as μ/μ_0; whereas, more strictly, it should be $(\mu/\mu_0) - 1$. In cases, however, where the core is either very slightly magnetised, or powerfully magnetised, near to saturation, it may happen that μ_m, the metallic permeability, is not large with reference to μ_0, the space permeability, and the correction may then be important.

Magnetic permeabilities vary considerably in different magnetic samples, unless the physical and chemical states are kept within narrow limits of specification. It is therefore necessary to measure the permeability experimentally, either directly or indirectly. A convenient device for this purpose is the well known closed circular solenoid, such as is shown in fig. 1, with rectangular cross section of core, prepared from the ferric material to be tested, and overwound with a known number of turns of insulated wire. In this way, the total flux density B in the core can be determined. The results may be presented in the form of a plane curve. Four types of such curves are available; namely: (a) H–B curves, or curves of flux-density B as a function of magnetic intensity H; (b) B-μ curves; (c) H-μ curves; and (d) H–ν curves. Of these four, the simplest is the H-ν curve. It is known that

the metallic reluctivity ν_m of magnetic materials, when plotted as ordinates against magnetising force H, follows approximately a pair of straight lines, connected at their convergence by a somewhat rounded elbow.[1]

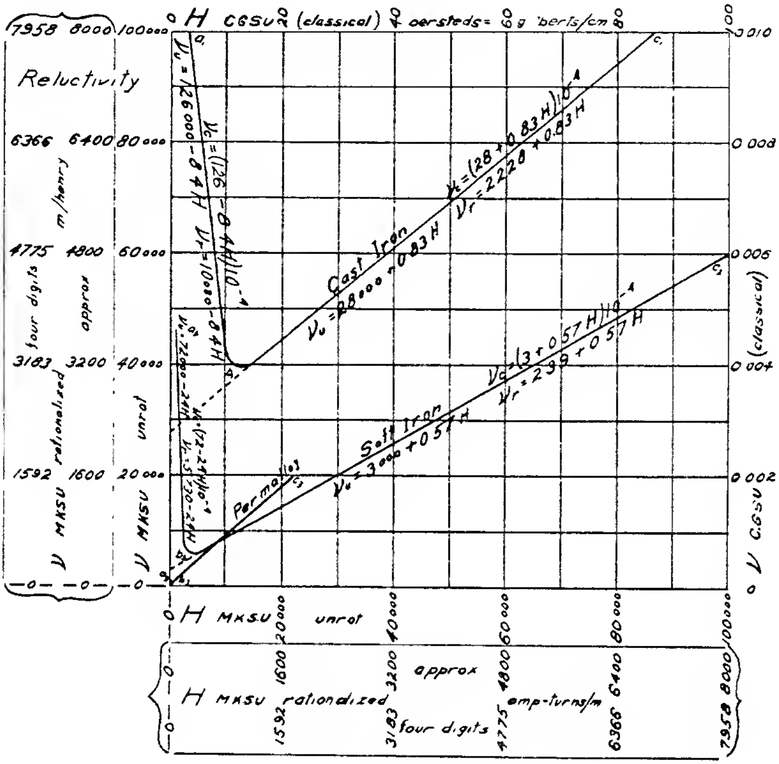

Fig 2
H – ν curves for samples of cast iron, soft iron and permalloy

Fig. 2 is an $H-\nu_m$ diagram for three particular samples of well known magnetic materials: cast iron, soft Norway iron, and permalloy. H is given in classical C.G.S. units (*œrsteds* or *gilberts cm.*), M.K.S. units unrationalised (anonymous), and M.K.S. units rationalised (*amp.-turns m.*). These last

[1] "Magnetic Reluctance," by A. E. Kennelly, *Trans. A.I.E.E.*, Oct., 1891, Vol. 8, p. 485. "The Reluctivity of the Recently Discovered Metal, Permalloy," *Jour. of the Franklin Inst.*, May, 1924, pp. 623–627.

are given both in round numbers, for $4\pi \cong 12.5$, and, more nearly correctly, to four digits ($4\pi = 12.57$). For many purposes the rounded values will be sufficient. The various values of ν are also given in C.G.S. units (anonymous), in M.K.S. unrationalised units (anonymous), and in M.K.S. rationalised units (*meters/henry*), the latter both in round numbers and in four-digit numbers. The bilinear curve $a_1b_1c_1$ pertains to cast iron average samples, $a_2b_2c_2$ to soft iron, and $a_3b_3c_3$ to permalloy. The following table expresses the H–ν_m relations.

TABLE I

RATIONALISED M.K.S.U.

Material	Range of H *amp.-turns/m.*	Descending ν_m *m./henry*	Range of H *amp.-turns/m.*	Ascending ν_m *m./henry*	
Cast iron	0–800	$10{,}030 - 8.4H$	1000–8000	$2228 + 0.83H$	(49)
Soft iron . . .	0–250	$5{,}730 - 24\ H$	400–8000	$239 + 0.57H$	(50)
Permalloy. . . .	0– 3	$76 - 22.5H$	5–1600	$4 + 0.91H$	(51)

Example (XIV). A closed ferric circular solenoid has a mean circumference of $l = 1.5$ *m.*, and a core cross-sectional area of $s = 4$ *cm.*^{2}. The soft iron core is wound with 1500 turns of insulated wire. The steady exciting current is 3.183 *amps.* Find the magnetic circuit conditions, assuming the reluctivity ν_m to be according to fig. 2.

The data for this case are presented in table II, with parallel columns. Column 4 gives the values in classical or unrationalised C.G.S. magnetic units. Column 5 shows the same data expressed in M.K.S. rationalised units, and Column 6 in M.K.S. unrationalised units. The reason for selecting the particular current strength as 3.183 *amps.*, instead of a round number of *amps.*, is that the magnetising force H thus comes out in round C.G.S. numbers (40 *œrsteds*). It will be seen that names are available for all of the units in Column 5, whereas internationally adopted names are missing for most of the units in Column 6, and for half of those in Column 4.

TABLE II

ANALYSIS OF TOROIDAL FERRIC CIRCUIT OF EXAMPLE (XIV)

1	2	3	4	5	6
No.	Quantity	Symbol	Classical C.G.S.U. $l = 150$ *cm.* $s = 4$ *cm.*^{2} $V = 600$ *cc.*	Rat. M.K.S.U. $l = 1.5$ *m.* $s = 4 \times 10^{-4}$ *m.*^{2} $V = 6 \times 10^{-4}$ *m.*^{3}	Unrat. M.K.S.U. $l = 1.5$ *m.* $s = 4 \times 10^{-4}$ *m.*^{2} $V = 6 \times 10^{-4}$ *m.*^{3}
1	Exc. Current	I	0.3183 :::	3.183 *amps.*	3.183 *amps.*
2	M.M.F.	M	$4\pi NI = 12.57 \times 1500 \times 0.3183 = 6000$ *gilberts*	$NI = 1500 \times 3.183 = 4775$ *amp.-turns*	$4\pi NI = 12.57 \times 1500 \times 3.183 = 60{,}000$ :::
3	Mag. Force	H	$M/l = 6000/150 = 40$ *œrsteds*	$M/l = 4775/1.5 = 3183$ *amp.-turns/m.*	$M/l = 60{,}000/1.5 = 40{,}000$ :::
4	Metallic Reluctivity	ν_m	$a_2+b_2H = (3 + 0.57 \times 40) \times 10^{-4} = 0.00258$ :::	$a_2 + b_2H = (239 + 0.57 \times 3183) = 2053$ *m./henry*	$a_2 + b_2H = (3000 + 0.57 \times 40{,}000) = 25{,}800$ :::
5	Metallic Permeability	μ_m	$1/\nu_m = 1/0.00258 = 387.6$ :::	$1/\nu_m = 1/2053 = 487.1 \times 10^{-6}$ *henry/m.*	$1/\nu_m = 1/25{,}800 = 387.6 \times 10^{-7}$ :::
6	Space Abs. Permeability	μ_0	1 :::	$4\pi \times 10^{-7} = 1.257 \times 10^{-6}$ *henry/m.*	10^{-7} :::
7	Total Abs. Permeability	μ	388.6 :::	488.4×10^{-6} *henry/m.*	388.6×10^{-7} :::
8	Relative Permeability	μ/μ_0	388.6 *numeric*	388.6 *numeric*	388.6 *numeric*
9	Total Permeance	$\mathcal{P}$	$\mu s/l = 388.6 \times 4/150 = 10.36$ :::	$\mu s/l = 4.884 \times 10^{-4} \times 4 \times 10^{-4}/1.5 = 1.302 \times 10^{-7}$ *weber/amp.-turn*	$\mu s/l = 3.886 \times 10^{-5} \times 4 \times 10^{-4}/1.5 = 1.036 \times 10^{-8}$ :::
10	Total Reluctance	$\mathcal{R}$	$1/\mathcal{P} = 1/10.36 = 0.9653 \times 10^{-1}$ :::	$1/\mathcal{P} = 1/(1.302 \times 10^{-7}) = 0.768 \times 10^{7}$ *amp.-turns/weber*	$1/\mathcal{P} = 1/(1.036 \times 10^{-8}) = 0.9653 \times 10^{8}$ :::
11	Total Flux	Φ	$M\mathcal{P} = 6000 \times 10.36 = 6.216 \times 10^{4}$ *maxwells*	$M\mathcal{P} = 4775 \times 1.302 \times 10^{-7} = 6.216 \times 10^{-4}$ *weber*	$M\mathcal{P} = 60{,}000 \times 1.036 \times 10^{-8} = 6.216 \times 10^{-4}$ *weber*

TABLE II—(*Continued*)

1	2	3	4	5	6
No.	Quantity	Symbol	Classical C.G.S.U. $l = 150$ *cm* $s = 4$ *cm.*² $V = 600$ *cc*	Rat. M.K.S.U. $l = 1.5$ *m* $s = 4 \times 10^{-4}$ *m.*² $V = 6 \times 10^{-4}$ *m.*³	Unrat. M.K.S.U. $l = 1.5$ *m.* $s = 4 \times 10^{-4}$ *m.*² $V = 6 \times 10^{-4}$ *m.*³
12	Total Flux Density	B	$\mu H = 388.6 \times 40 = 1.554 \times 10^4$ *gauss*	$\mu H = 488.4 \times 10^{-6} \times 3183 = 1.554$ *webers/m.*²	$\mu H = 388.6 \times 10^{-7} \times 40{,}000 = 1.554$ *webers/m.*²
13	Volume Energy	w	$HB/8\pi = 40 \times 1.554 \times 10^4/25.13 = 2.473 \times 10^4$ *ergs/cc*	$HB/2 = 3183 \times 1.554/2 = 2.473 \times 10^3$ *joule/m.*³	$HB/8\pi = 40{,}000 \times 1.554/25.13 = 2.473 \times 10^3$ *joules/m.*³
14	Total Mag. Energy	W	$Vw = 600 \times 2.473 \times 10^4 = 1.484 \times 10^7$ *ergs*	$Vw = 6 \times 10^{-4} \times 2.473 \times 10^3 = 1.484$ *joules*	$Vw = 6 \times 10^{-4} \times 2.473 \times 10^3 = 1.484$ *joules.*
15	Inductance	$\mathfrak{L}$	$N\Phi/I = 1.5 \times 10^3 \times 6.216 \times 10^4/0.3183 = 2.929 \times 10^8$ *cms*	$N\Phi/I = 1.5 \times 10^3 \times 6.216 \times 10^{-4}/3.183 = 0.2929$ *henry*	$N\Phi/I = 1.5 \times 10^3 \times 6.216 \times 10^{-4}/3.183 = 0.2929$ *henry*
16	Electromag. Energy of Winding	W	$\mathfrak{L}I^2/2 = 2.929 \times 10^8 \times 0.3183^2/2 = 1.484 \times 10^7$ *ergs*	$\mathfrak{L}I^2/2 = 0.2929 \times 3.183^2/2 = 1.484$ *joules*	$\mathfrak{L}I^2/2 = 0.2929 \times 3.183^2/2 = 1.484$ *joules*

Fig. 3 presents the H–B diagram for the particular sample of soft iron whose H–ν_m curve is given in fig. 2. The abscissæ of fig. 3 are expressed in C.G.S. *œrsteds*, in M.K.S. *ampere-turns per meter*, and in M.K.S. unrationalised units. The ordinates are likewise expressed in C.G.S. *gauss*, and in M.K.S. *webers m.*². It will be seen that at $H = 100$ *œrsteds*, or approximately 8000 *amp.-turns/m.*, or 100,000 *unrat. M.K.S. units*, the iron is approaching magnetic saturation.

The following conversion rules to rat. units are useful.

TABLE III

1	Multiply no. of *gilberts*	by 0.8 to express $\mathfrak{F}$ or	M	in *amp.-turns*
2	Multiply no. of *œrsteds*	by 80	to expr. H	in *amp.-turns/m.*
3	Multiply no. of C.G.S.U. of μ	by 1.257×10^{-6}	to expr. μ	in *henrys/m.*
4	Multiply no. of C.G.S.U. of ν	by 0.8×10^6	to expr. ν	in *m./henry*
5	Multiply no. of C.G.S.U. permeance	by 1.257×10^{-8}	to expr. $\mathfrak{P}$	in *web./amp.-turn*
6	Multiply no. of C.G.S.U. reluctance	by 0.8×10^8	to expr. $\mathfrak{R}$	in *amp.-turns/web.*
7	Multiply no. of *maxwells*	by 10^{-8}	to expr. Φ	in *webers*
8	Multiply no. of *gausses*	by 10^{-4}	to expr. B	in *webers/m.*²
9	Multiply no. of *ergs/cc*	by 10^{-1}	to expr. w	in *joules/m.*³
10	Multiply no. of *ergs*	by 10^{-7}	to expr. W	in *joules*
11	Multiply no. of C.G.S.U. inductance	by 10^{-9}	to expr. $\mathfrak{L}$	in *henrys*

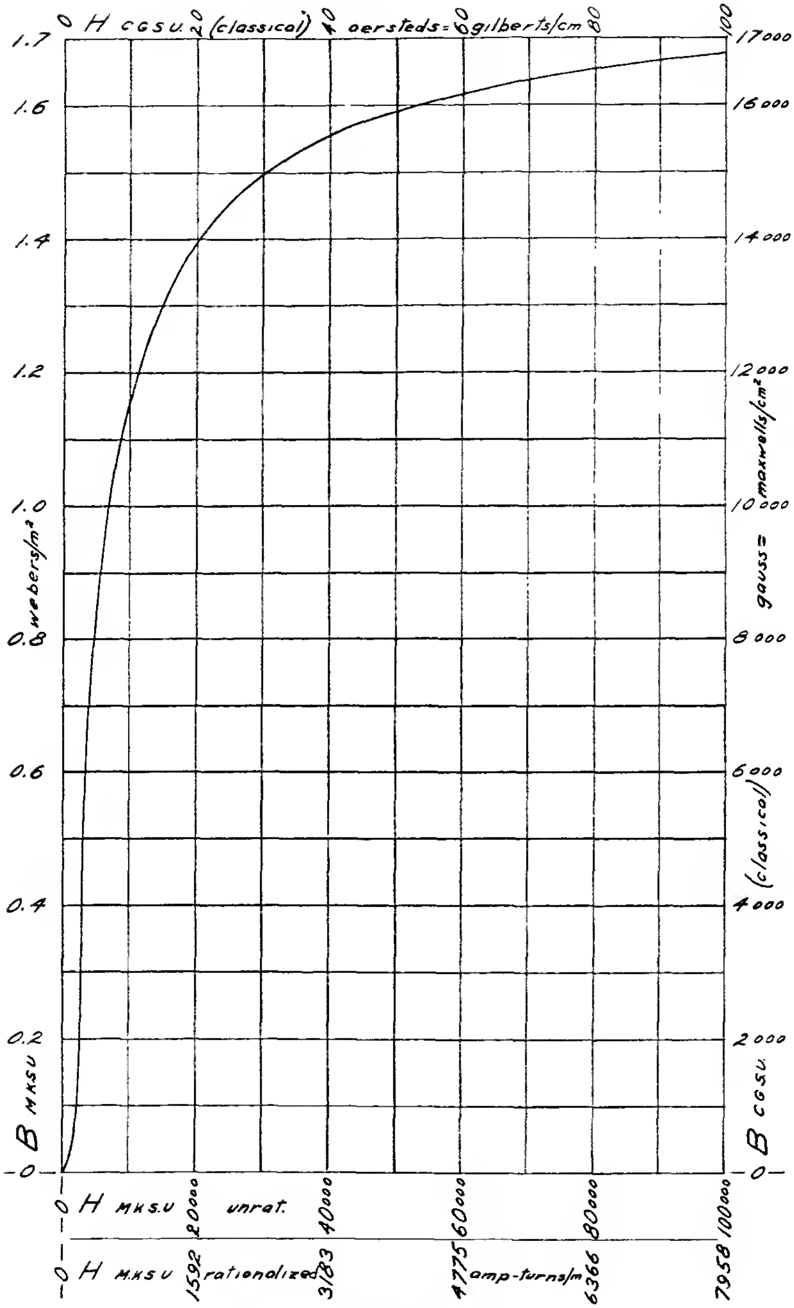

Fig. 3
H-B curve for sample of soft iron.

In entries 1, 2, 4 and 6 of the table III, the digit 8 is an approximation for the four-digit expression 7.958.

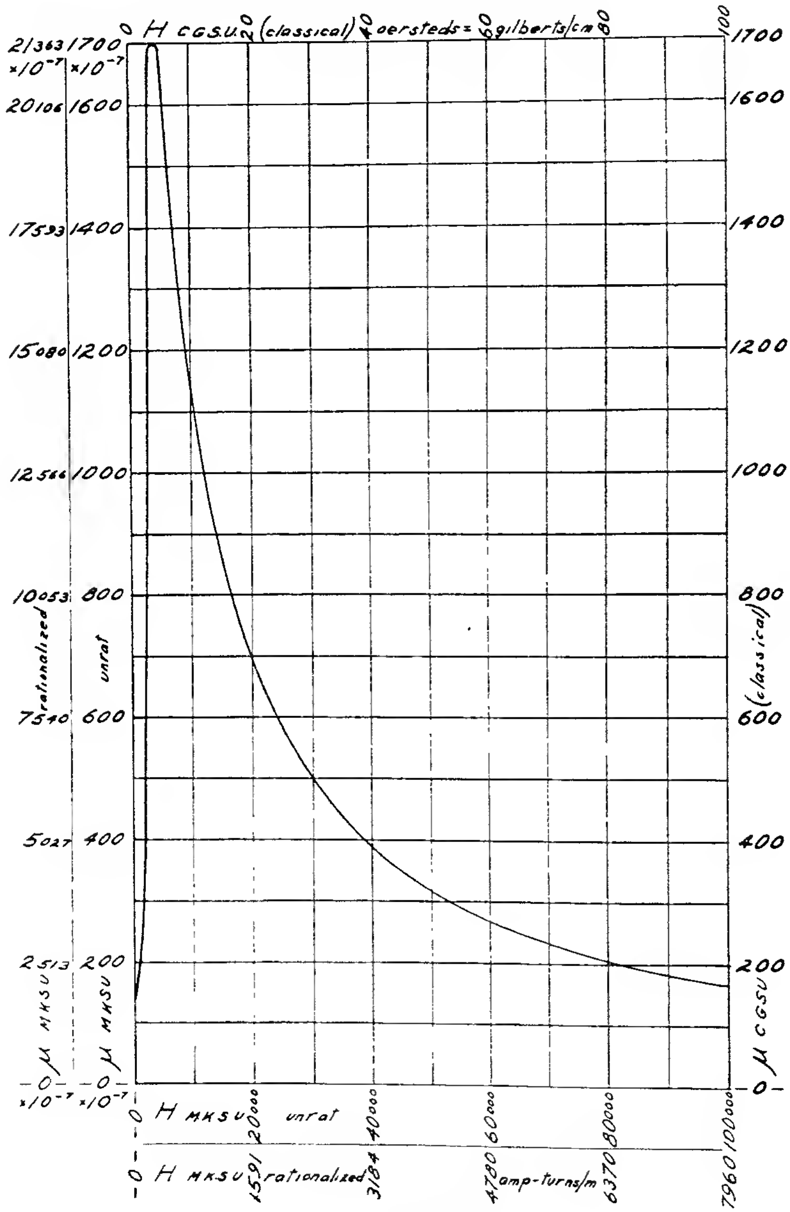

Fig 4.
H-μ curve for sample of soft iron.

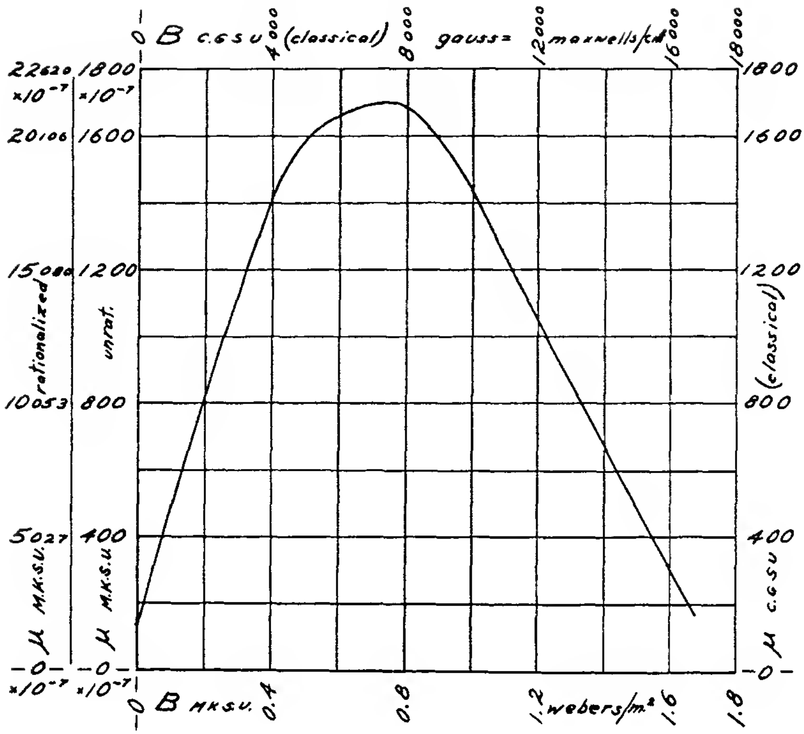

Fig. 5.
B-μ curve for sample of soft iron.

Figs. 4 and 5 show respectively the H–μ and B–μ curves for the same sample of soft iron represented by the bilinear curve of fig. 2. The coördinates are given in classical C.G.S.U., and in M.K.S.U. both rationalised and unrationalised. In fig. 4, the maximum or peak value of μ occurs at the value of H in fig. 2 where the elbow connects the descending and ascending lines of reluctivity.

Table IV gives names and relative values to the units of absolute permeability in the different systems.

The rules for computing the magnetic circuit in dynamo design, in terms of reluctivity ν and reluctance $\mathcal{R}$, or of permeability μ and permeance $\mathcal{P}$, are concordant in the C.G.S. and M.K.S. systems; so that in view of the last two

TABLE IV

No.	System	Permeability Unit Name	C.G.S.U. Value	Reciprocal Value
1	C.G.S.	* *Abhenry/cm.*	1	1
2	M.K.S. rat. . . .	*Henry/m.*	$10^7/4\pi$	$4\pi \times 10^{-7}$
3	M.K.S. unrat. . . .	*Henry/m.*	10^7	10^{-7}
4	Q.E.S.† . . .	*Henry/quadrant*	1	1

* The term *abhenry* here means the name of the unit of inductance in the classical or unrationalised C.G.S. system. The prefix "ab" for designating C.G.S.U. corresponding to M.K.S.U. has not been accepted internationally. It has some usage in the United States.

† Quadrant Eleventh-gram Second.

Examples, M.K.S. dynamo design presents no serious difficulty. The numerical ratios of relative permeability and of leakage coefficient are identical in both systems.

Magnetomechanical Attraction. Lifting Electromagnets

When two opposed parallel polar magnetic surfaces are separated by a thin air-gap or entrefer, so that the flux density across this gap is uniform at B *webers/m.*², the areal attractive force, or mechanical pull magnetically exerted between the polar surfaces per unit of area, is likewise uniform, and is expressed by the symbolically independent group of formulæ:

$$f = H\mathfrak{J}/2 \qquad \textit{joules/m. per m.}^2, \qquad (52)$$

where $\mathfrak{J}$ is the intensity of magnetisation of the pole faces or polar quantity per unit area *m/s*. In detail, this formula is dependent:

Rationalised	*Unrationalised*
$f = HB/2 = H^2\mu_0/2$	$f' = H'B/8\pi = H'^2\mu_0'/8\pi$
$= B^2/2\mu_0$ *joules/m.*³. (53)	$= B^2/8\pi\mu_0'$ *joules/m.*³. (53)

The total tractive force exerted obeys the independent formula:

$$F = sf \qquad \textit{joules/m.}, \qquad (54)$$

where s is the active polar surface area on each side of the entrefer.

Example (XV). A bipolar electromagnet of soft iron has 10 $cm.^2$ (10^{-3} $m.^2$) of active polar surface on each pole. The armature is a smooth flat bar of soft iron placed across the poles and separated therefrom by a uniform entrefer of 1 *mm.* The flux density across the entrefer is uniform at $B = 18{,}000$ *gauss* (1.8 *webers*/$m.^2$). Find the total tractive force exerted between the electromagnet and armature.

TABLE V

TRACTIVE FORCE OF BIPOLAR ELECTROMAGNET OF EXAMPLE (XV)

Quantity	Classical C.G.S.U.	Rationalised M.K.S.U.	Unrat. M.K.S.U.
Flux Density B	18,000 *gauss*	1.8 *webers*/$m.^2$	1.8 *webers*/$m.^2$
Gap Permeability μ_0	1 :::	$4\pi \times 10^{-7} = 1.256 \times 10^{-6}$ *henry*/*m.*	10^{-7} :::
Active Polar Area	10 $cm.^2$ per pole	10^{-3} $m.^2$ per pole	10^{-3} $m.^2$ per pole
Gap Magnetic Intensity $H = B/\mu_0$	18,000 *œrsteds*	1.432×10^6 *amp.-turns*/*m.*	1.8×10^7 :::
Areal Force f	$HB/8\pi = 18{,}000^2/25.13 = 1.289 \times 10^7$ *dynes*/$cm.^2$	$HB/2 = 1.432 \times 10^6 \times 1.8/2 = 1.289 \times 10^6$ *joules*/$m.^3$	$HB/8\pi = 1.8 \times 10^7 \times 1.8/25.13 = 1.289 \times 10^6$ *joules*/$m.^3$
Total Force per Pole $F = sf$	$10 \times 1.289 \times 10^7 = 1.289 \times 10^8$ *dynes*	$10^{-3} \times 1.289 \times 10^6 = 1.289 \times 10^3$ *joules*/*m.*	$10^{-3} \times 1.289 \times 10^6 = 1.289 \times 10^3$ *joules*/*m.*
Total Bipolar Force $2F$	2.578×10^8 *dynes*	2.578×10^3 *joules*/*m.*	2.578×10^3 *joules*/*m.*
Total Weight Pull	$2F/981 = 2.628 \times 10^5$ *gm.*	$2F/9.81 = 262.8$ *kg.*	$2F/9.81 = 262.8$ *kg.*

The total pull is here independent of the width of the airgap provided that the flux density can be kept uniform at 1.8 *webers*/*m.* In practice, unless the airgap is very thin, this becomes impracticable.

Cyclic Energy of Hysteresis

It is well known that when magnetic material is subjected to cyclic reversals of magnetisation, magnetic energy is expended within the material as heat, owing to hysteresis, or the persistent lagging of the flux density B behind the impressed reversing magnetising force H.

If we subject the material, in the form of a toroidal ring core, to successive slow reversals of m.m.f. M, and measure, stage by stage, the flux Φ in the ring, we may produce a Ewing H–B loop diagram, characteristic of the material, for the particular limits chosen for the reversals of H, as shown in fig. 6.

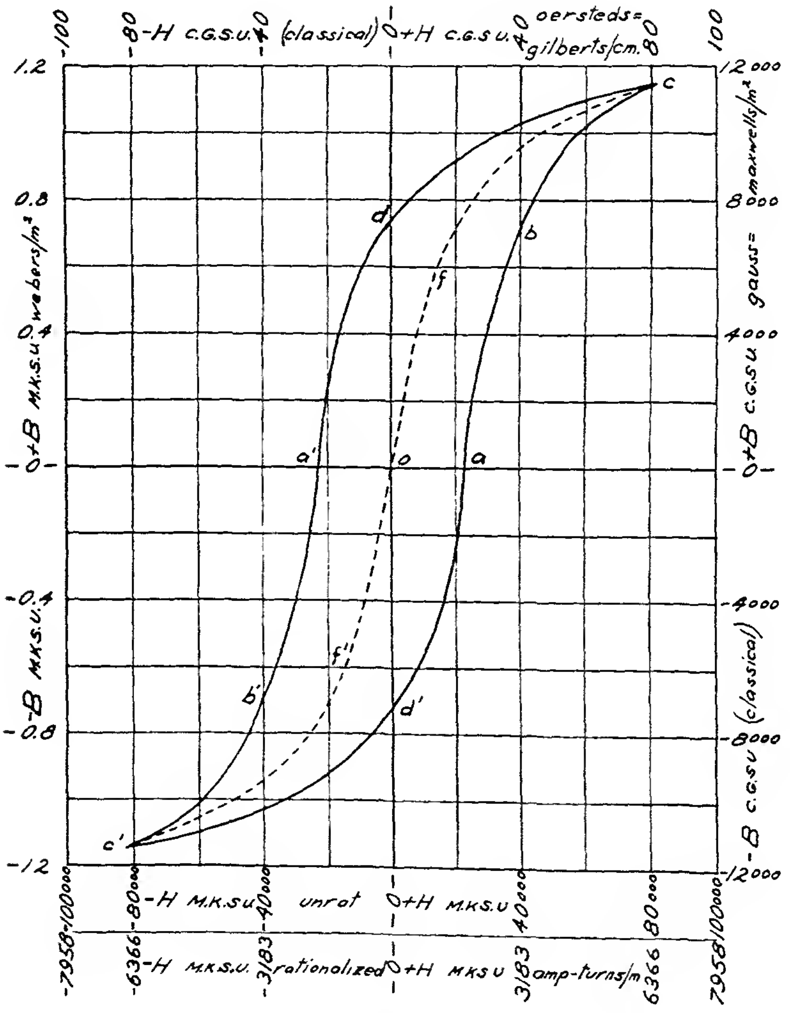

Fig. 6.
H-B Hysteresis Loop

This diagram is the hysteresis loop for a sample of hard cast steel, subjected to slow reversals of magnetising force between $H = -82$ and $+82$ *œrsteds* or *gilberts per cm.* If there were no hysteretic loss of energy during this process, the flux density B might be expected to move to-and-fro along the single broken curve $c'f'ofc$, whereas the observed curve is the loop $abcda'b'c'd'$, executed once in each cycle. It is shown in magnetic textbooks that the greater the area inclosed by the loop, the greater, in direct proportion, will be the cyclic loss of energy per unit of volume. This hysteretic loss of energy into heat is relatively small for soft iron, and relatively large for hard steel. If $\int H \cdot dB$ represents the area of the loop in *œrsted-gauss*, the C.G.S. loss of energy is

$$w = (1/4\pi)\int H \cdot dB \qquad ergs/cycle \cdot cm.^3. \qquad (55)$$

The corresponding dependent M.K.S. formulæ are:

Rationalised	*Unrationalised*
$w = \int H \cdot dB$ $\quad joules/cycle \cdot m.^3. \quad (56)$	$w' = (1/4\pi)\int H' \cdot dB$ $\quad joules/cycle \cdot m.^3. \quad (56)$

The measurement of the loop area ordinarily calls for the use of a planimeter; but fig. 7 presents a simplified ideal form of H–B loop, the area of which can be readily determined by inspection. The loop is a simple parallelogram $dcd'c'$. Its reduction to volume energy per cycle is given in table VI.

TABLE VI

HYSTERETIC VOLUME ENERGY FOR SIMPLIFIED H-B LOOP OF FIG. 7

C.G.S.U.				M.K.S.U.							
				Rationalised				*Unrationalised*			
H	B	Area	Energy	H	B	Area	Energy	H'	B	Area	Energy
œrsteds	*gauss*	$H \cdot B$	*ergs/c.c.*	*amp.-turns/m.*	*webers/m.²*	$H \cdot B$	*joules/m.³*	...	*webers/m.²*	$H' \cdot B$	*joules/m.³*
40	24,000	960,000	76,370	3182	2.4	7637	7637	40,000	2.4	96,000	7637

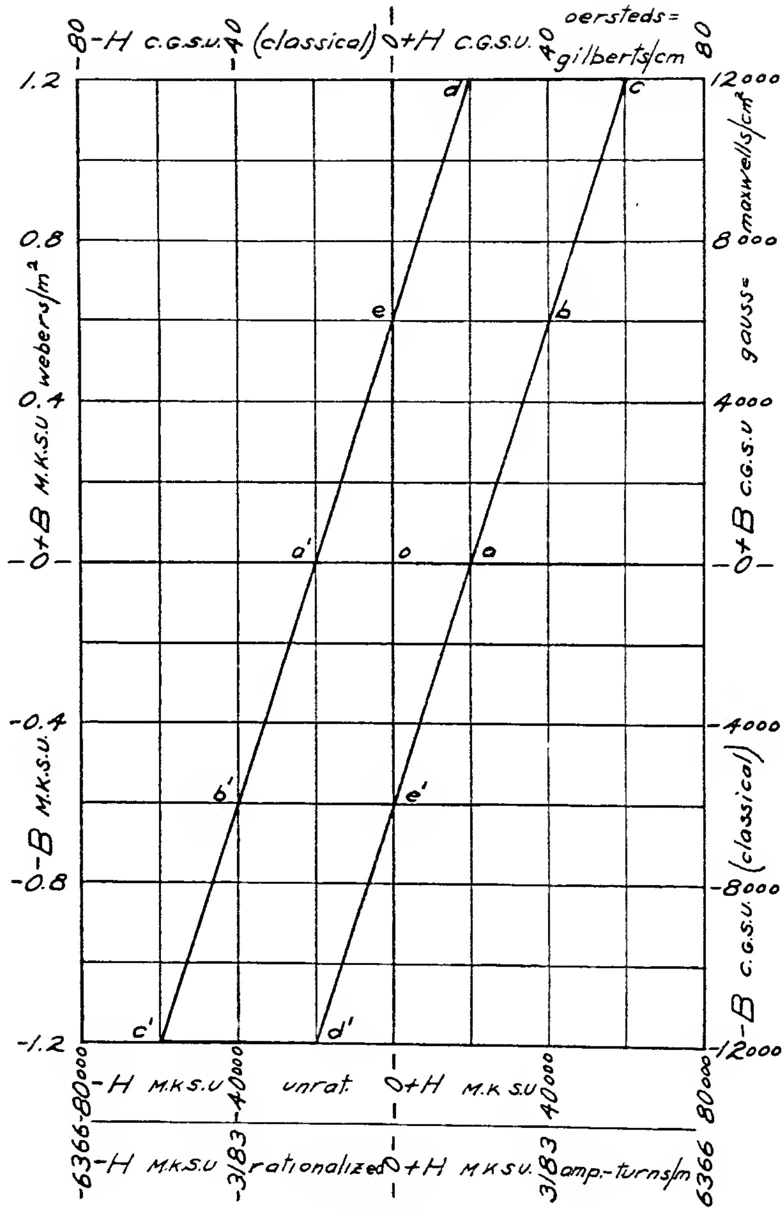

Fig. 7
Simplified Ideal H-B Hysteresis Loop.

The heat expended in the corresponding sample would therefore be 7637 *joules per cubic meter per cycle*, or 7637 *microjoules per cubic centimeter per cycle.*

Table VII serves to convert classical C.G.S.U. and rationalised M.K.S.U.

TABLE VII

No.	Symbol and Definition	1 C.G.S. Magnetic Unit = n M.K.S. Rationalised Units	1 M.K.S. Rationalised Unit = $1/n$ C.G.S. Magnetic Units
1	$M = \alpha NI$	1 *gilbert* = 0.7958 *amp.-turns*	1 *amp.-turn* = 1.257 *gilberts*
2	$\mathcal{R} = lv/s$	1 C.G.S.U. of Reluctance = 0.7958×10^8 *amp.-turns/weber*	1 *amp.-turn/weber* = 1.257×10^{-8} :::
3	$\mathcal{P} = \mu s/l$	1 C.G.S.U. of Permeance = 1.257×10^{-8} *webers/amp.-turn*	1 *weber/amp.-turn* = 0.7958×10^8 :::
4	$\Phi = M\mathcal{P}$	1 *maxwell* = 10^{-8} *weber*	1 *weber* = 10^8 *maxwells*
5	$B = \Phi/s$	1 *gauss* = 10^{-4} *weber/m.*^{2}	1 *weber/m.*^{2} = 10^4 *gauss*
6	$H = M/l$	1 *œrsted* = 79.58 *amp.-turns/m.*	1 *amp.-turn/m.* = 1.257×10^{-2} *œrsted*
7	$\mu = \mathcal{L}/l$	1 C.G.S.U. of Permeability = 1.257×10^{-6} *henry/m.*	1 *henry/m.* = 0.7958×10^6 :::
8	$\nu = l/\mathcal{L}$	1 C.G.S.U. of Reluctivity = 0.7958×10^6 *m./henry*	1 *m./henry* = 1.257×10^{-6} :::
9	$m = f/H$	1 C.G.S. *pole* = 1.257×10^{-7} *weber*	1 *weber* = 0.7958×10^7 C.G.S. *poles*
10	$\mathfrak{J} = m/s$	1 C.G.S.U. of Intensity of Magnetisation = 1.257×10^{-3} *weber/m.*^{2}	1 *weber/m.*^{2} = 0.7958×10^3 :::
11	$\mathfrak{M} = ml$	1 C.G.S.U. of Magnetic Moment = 1.257×10^{-9} *weber-m.*	1 *weber-m.* = 0.7958×10^9 :::

Table VIII is likewise available for the conversion of classical C.G.S. magnetic units and unrationalised M.K.S. units.

TABLE VIII

No.	Symbol and Definition	1 C.G.S. Magnetic Unit = n M.K.S. Unrationalised Units	1 M.K.S. Unrationalised Unit = $1/n$ C.G.S. Magnetic Units
1	$M = 4\pi NI$	1 *gilbert* = 10 M.K.S.U. :::	1 M.K.S.U. ::: = 10^{-1} *gilbert*
2	$\mathfrak{R} = l\nu/s$	1 C.G.S.U. of Reluctance = 10^{9} M.K.S.U. :::	1 M.K.S.U. of Reluctance = 10^{-9} C.G.S.U. :::
3	$\mathcal{P} = \mu s/l$	1 C.G.S.U. of Permeance = 10^{-9} M.K.S.U. :::	1 M.K.S.U. of Permeance = 10^{9} C.G.S.U. :::
4	$\Phi = M\mathcal{P}$	1 *maxwell* = 10^{-8} *weber*	1 *weber* = 10^{8} *maxwells*
5	$B = \Phi/s$	1 *gauss* = 10^{-4} *weber/m.²*	1 *weber/m.²* = 10^{4} *gauss*
6	$H = M/l$	1 *œrsted* = 10^{3} M.K.S.U. :::	1 M.K.S.U. of Magnetising Force = 10^{-3} *œrsted*
7	$\mu = \mathfrak{L}/l$	1 C.G.S.U. of Permeability = 10^{-7} M.K.S.U. :::	1 M.K.S.U. of Permeability = 10^{7} C.G.S.U. :::
8	$\nu = l/\mathfrak{L}$	1 C.G.S.U. of Reluctivity = 10^{7} M.K.S.U. :::	1 M.K.S.U. of Reluctivity = 10^{-7} C.G.S.U. :::
9	$m = j/H$	1 C.G.S. *pole* = 10^{-5} M.K.S. *pole*	1 M.K.S. *pole* = 10^{5} C.G.S. *poles*
10	$\mathfrak{I} = m/s$	1 C.G.S.U. of Intensity of Magnetisation = 10^{-4} M.K.S.U. :::	1 M.K.S.U. of Intensity of Magnetisation = 10^{4} C.G.S.U. :::
11	$\mathfrak{M} = ml$	1 C.G.S.U. of Magnetic Moment = 10^{-10} M.K.S.U. :::	1 M.K.S.U. of Magnetic Moment = 10^{10} C.G.S.U. :::

ACKNOWLEDGMENTS

The author is indebted to Mr. B. I. Small for help in preparing the material and illustrations for this paper.

TABLE IX

LIST OF SYMBOLS EMPLOYED

		Unrat. M.K.S.U.	Rat. M.K.S.U.	C.G.S.U.
B	Flux density	*webers/m*^{2}	*webers/m*^{2}	*gauss*
d	Differential			
E	Effective e.m.f.	*volts*	*volts*	:::
E_m	Maximum cyclic e.m.f.	*volts*	*volts*	:::
e	Instantaneous induced e.m.f.	*volts*	*volts*	:::
F	Total mechanical force	*joules/m.*	*joules/m.*	*dynes*
f	Linear mechanical force	*joules/m.*^{2}	*joules/m.*^{2}	*dynes/cm.*
f	Areal mechanical force	*joules/m.*^{3}	*joules/m.*^{3}	*dynes/cm.*^{2}
f, $\sim$	Frequency of alternation	*cycles/sec.* or *hertz*	*cycles/sec.* or *hertz*	*cycles/sec.* or *hertz*
$\mathfrak{F}$ or M	Magnetomotive force	:::	*amp.-turns*	*gilberts*
H	Magnetising force	:::	*amp.-t./m.*	*œrsteds*
I, i	Current strength	*amperes*	*amperes*	:::
$\mathfrak{I}$	Magnetisation intensity	:::	*webers/m.*^{2}	:::
κ	Magnetic susceptibility	:::	:::	:::
$\mathfrak{L}$	Inductance of winding	*henrys*	*henrys*	:::
l	Length	*m.*	*m.*	*cm.*
$\mathfrak{M}$	Magnetic moment	:::	*weber-m.*	:::
m	Magnetic quantity, pole strength	:::	*webers*	:::
μ_0	Space permeability	:::	*henrys/m.*	:::
μ_m	Metallic absolute permeability	:::	*henrys/m.*	:::
μ	Total absolute permeability	:::	*henrys/m.*	:::
μ/μ_0	Relative permeability	numeric	numeric	numeric
N	Total number of wires	numeric	numeric	numeric
n	Linear turns of winding	*turns/m.*	*turns/m.*	*turns/cm.*
n	Angular velocity	*revs./sec.*	*revs./sec.*	*revs./sec.*
ν_0	Space reluctivity	:::	*m./henry*	:::
ν_m	Metallic reluctivity	:::	*m./henry*	:::
P	Active power	*watts*	*watts*	*ergs/sec.*
p	Number of pairs of poles	numeric	numeric	numeric
$\mathcal{P}$	Permeance	:::	*web./amp.-t.*	:::
π	3.1416	numeric	numeric	numeric
$\mathcal{R}$	Reluctance	:::	*amp.-t./web.*	:::
r	Radial distance from axis	*m.*	*m.*	*cm.*
s	Cross-sectional area	*m.*^{2}	*m.*^{2}	*cm.*^{2}
T, t	Time	*seconds*	*seconds*	*seconds*
τ	Torque	*joule/rad.*	*joule/rad.*	*erg/rad.*
v	Velocity	*m./sec.*	*m./sec.*	*cm./sec.*
Φ	Magnetic flux	*webers*	*webers*	*maxwells*
Φ_m	Max. cyclic mag. flux, metallic flux	*webers*	*webers*	*maxwells*
Φ_0	Space magnetic flux	*webers*	*webers*	*maxwells*
W	Total work or energy	*joules*	*joules*	*ergs*
W_e	Electromagnetic energy of winding	*joules*	*joules*	*ergs*
W_m	Magnetic energy of core	*joules*	*joules*	*ergs*
w	Volume energy	*joules/m.*^{3}	*joules/m.*^{3}	*ergs/cm.*^{3}
ω	Angular velocity	*rads./sec.*	*rads./sec.*	*rads./sec.*
$\backsimeq$	Approximate equality			
:::	Anonymous internationally			

REPORT OF THE COMMITTEE ON RESEARCH

EDWIN G. CONKLIN

Chairman

Presented at the General Meeting of the Society April 24, 1936

In view of the fact that three years have passed since the Society authorized the establishment of the committee on research and since previous annual reports have not been published, it seems advisable at this time to review the work of these three years and to summarize the results. The charter under which this committee is acting is contained in the following resolution recommended by the committee on policy and adopted by the Society at the general meeting, April 20, 1933: "*Resolved*, that a Standing Committee of at least five members representing the several fields of knowledge be appointed by the Council to make recommendations in regard to appropriations for the advancement of knowledge through investigation." On June 14, 1933, the council appointed the following members of this committee: President, Roland S. Morris, Vice-president, Edwin G. Conklin, Secretary, John A. Miller, Dr. Karl T. Compton, Dr. James T. Young. At the same time the council authorized the finance committee to include in the budget the sum of $50,000 a year for grants in aid of research.

The committee organized with Dr. Conklin as chairman, and early in 1934 adopted a series of general principles and rules defining its purposes and plan of operation, a blank form of application for grants, and a form of agreement to be entered into by each recipient of a grant. These were printed and submitted to the Society at its general meeting in 1934, and they have been in use ever since.

President Compton and Professor Young found it necessary to retire from the committee after nearly two years of faithful and often laborious service, and their places have been

taken by Dr. W. F. G. Swann and Secretary William E. Linglebach. Dr. Hugh S. Taylor and Dr. Isaiah Bowman were added to the committee one year ago.

Since its organization the committee has met every two months from October to June, inclusive. Applications and supporting recommendations are manifolded and sent to each member of the committee several days before the stated meeting at which they are to be considered. The members of the committee have taken their duties seriously and in some cases have interviewed the applicants or some of their sponsors in attempting to assess the merits of the applications. Whenever the committee has been in doubt about the merits of a particular application, it has sought and obtained the advice of scholars expert in that field; the committee is deeply indebted to the many persons who have thus aided it.

The total number of applications received and considered by the committee since its organization is 214, and the total amount requested was nearly $400,000. Somewhat more than 100 applications were received during the first two years, and slightly less than 100 during the past year.

Each year since the organization of this committee, the finance committee, on recommendation of the council, has budgeted a specific sum for grants in aid of research. In 1933 this sum was $20,000, in 1934 $45,000, in 1935 $60,000, in 1936 $50,000. There has thus been placed at the disposal of the committee on research, for the four years named, a total sum of $175,000.

Altogether 98 grants have been made of an aggregate sum of $147,670. Of this sum $125,467.41 has been actually paid out, while $22,202.59 is still in the hands of the treasurer awaiting distribution to applicants. Miscellaneous expenses have amounted to $225.96, leaving a balance for distribution during the remainder of 1936 of $27,104.05. A list of all grants made hitherto follows:

1933, July 26

Grant No. 1—Thomas C. Poulter, Byrd Antarctic Expedition II, to make echo sounding equipments available for measuring depth of polar ice cap and discovering nature of its basic support $3,000

1933, November 17

Grant No. 2—Horace Elmer Wood, 2nd, Dana College, Newark, N. J., to assist in the prosecution of his research and publications on the anatomy, stratigraphic distribution and phylogeny of the rhinoceroses and related groups of perissodactyls 500

1934, January 13

Grant No. 3—Warren K. Moorehead, Andover, Mass., to help finance his work on the Amerinds of New England 50

Grant No. 4—William B. Scott, Princeton University, to enable him to prepare a monograph on the fossil mammals of the White River formation in Dakota and Nebraska 2,000

Grant No. 5—James T. Young, University of Pennsylvania, in support of the work of four assistants on a survey of local rural government in Pennsylvania 6,600

1934, March 10

Grant No. 6—Robert A. Millikan and John P. Buwalda, California Institute, in support of work on the physical determination of the geological time scale 2,000*

Grant No. 7—Alfred C. Lane, Tufts College, in support of a co-operative research in physics and chemistry on the relations of the various radioactive elements in rocks and the lead produced therefrom 1,200

Grant No. 8—Felix E. Schelling, acting for the Modern Language Association of America, for the editing of two plays (Richard II and 2 Henry IV) by Professors Black and Shaaber for the Variorum edition of Shakespeare 5,000

Grant No. 9—W. F. G. Swann, Bartol Institute, for investigations in nuclear physics 3,000

Grant No. 10—Academy of Natural Sciences of Philadelphia, (1) for collection and study of the distribution and sources of the avifauna of Bolivia by M. A. Carriker, Jr., (2) to collect and make field studies of plants in Northern Mexico by Francis W. Pennell, (3) to collect and make field studies of mollusks of northern states of Mexico from Nuevo Leon to Chihuahua by Henry A. Pilsbry 5,000

1934, April 16

Grant No. 11—P. W. Whiting, Cold Spring Harbor, N. Y., to enable him to continue his investigations on genetics and sex-determination in the parasitic wasp Habrobracon 500

Grant No. 12—George M. Reed, Brooklyn Botanic Garden, to enable him to carry on his work on the influence of the nutrition of the host on development of smuts 500

Grant No. 13—J. Lincoln Cartledge, Cold Spring Harbor, N. Y., to enable him to continue his investigation of the factors which are responsible for increased mutation rate in aged seeds of Datura 1,800

Grant No. 14.—A. V. Grosse, University of Chicago, to cover the cost of labor and other expenses involved in the extraction of 1 gram of the radio-active element 91, protactinium, from about 5 tons of raw material and its isolation in the form of pure salts and finally in the metallic state itself 1,500

Grant No. 15—Edward L. Thorndike, Columbia University, in support of a research in the psychology of animal and human learning 1,100

Grant No. 16—V. M. Slipher, the Lowell Observatory, for extending the search of the ecliptic, covering a wide belt of the sky, for outer members of the solar system 2,000

* $2000 transferred to Grant No. 66.

Grant No. 17—Edward L. Bowles and Henry G. Houghton, Jr., Massachusetts Institute of Technology, in support of a program of research on fog dissipation . . 2,500

Grant No. 18—Arthur J. Dempster, University of Chicago, in support of a more accurate determination of atomic weights by the methods of mass spectroscopy . . . 1,500

Grant No. 19—John R. Murlin, University of Rochester, an investigation of heat production of small animals by a new method of direct calorimetry 500

1934, June 5

Grant No. 20—H. H. F. Jayne, for the University of Pennsylvania Museum, to assist the Museum's work in archaeological excavations in the Manich River Valley of the Caucasus, in co-operation with the Academy of Sciences of Leningrad (Cancelled because of lack of co-operation) 1,800

Grant No. 21—Hellmut de Terra, Yale University for support, in co-operation with other institutions, of the study of the geological background of early man in Northern India by concerted methods of geology, paleontology, and prehistory, and to carry out an organized search for early hominids and fossil anthropoid apes for the advancement of our knowledge of man's evolution and his earliest cultures 3,000

Grant No. 22—Ralph E. Cleland, Goucher College, in support of a co-operative cytogenetic and taxonomic attack upon the phylogeny and systematics of Œnothera 1,500

Grant No. 23—F. K. Richtmyer, Cornell University, for laboratory assistance in the determination of the widths, shapes and relative intensities of the lines in the X-ray spectra of the several elements; and the use of these data to compute the distribution of energy in the excited states of atoms 1,500

Grant No. 24—Farrington Daniels and B. M. Duggar, University of Wisconsin, in support of a fundamental research in photosynthesis, concerned with a determination of the quantum efficiency in the process when employing monochromatic light in different regions of the spectrum, using algae as test material . . . 1,500

Grant No. 25—K. Lark-Horovitz, Purdue University, in support of work on the intensity of electron scattering by means of homeo-polar compounds 1,500

Grant No. 26—Harry Shultz Vandiver, University of Texas, for technical assistance in the computation and investigation of the properties of Bernoulli Numbers with special application to Fermat's last Theorem. 1,500

Grant No. 27—Frank G. Dunnington, California Institute, in support of a precision determination of the specific charge of a free electron by a new deflection method 1,500

1934, July 10

Grant No. 28—N. T. Bobrovnikoff, Ohio Wesleyan University, for investigations of stellar spectra, mostly in the red and infra-red, with special attention to the band spectra 2,000

1934, October 8

Grant No. 29—[illegible], Philadelphia Institute for Medical Research, in support of work on the biological effect of thymus extract (Hanson) in accelerating the rate of growth and development in successive generations . . 2,000

Grant No. 30—Frank C. J[illegible] Observatory, for assistance in [illegible] plates and computations for the determination of [illegible] . 1,000

1934, December

Grant No. 31—C. E. Mendenhall and G. Breit, University of Wisconsin, in support of experiments on nuclear disintegration and scattering with protons and deutons accelerated by about 300 k.v. . 800

Grant No. 32—Alexander Petrunkevitch, Yale University, to enable him to continue his work on the peculiar physiology of digestion and digestive enzymes in spiders 500

Grant No. 33—Charles E. Allen, University of Wisconsin, for the determination of the chromosome complements of heteroploid clones of Sphærocarpos. 750

Grant No. 34—Henry A. Pilsbry, Academy of Natural Sciences, Philadelphia, to enable him to collect and make field studies of mollusks of Sonora and Sinaloa, Northwestern Mexico, with the object of determining the relations of the Sonoran fauna of our southwest to the Neotropical fauna of Mexico 1,000

Grant No. 35—Francis W. Pennell, Academy of Natural Sciences, Philadelphia, to enable him to collect and make field studies of plants, especially of the family Scrophulariacea, in Sonora and Sinaloa, Northwestern Mexico, considering the composition and distribution of the flora, and its relation to that of the southwestern United States and southern Mexico 1,000

1935, February 15

Grant No. 36—Edgar B. Howard, University of Pennsylvania Museum, to investigate the problem of man's antiquity in America with particular reference to a study of possible routes of migrations from Asia 2,000

Grant No. 37—Frederica de Laguna, University of Pennsylvania Museum, to make an archæological investigation of the lower Yukon Valley from Koyukuk to Holy Cross, Alaska. 3,000

Grant No. 38—Charles P. Olivier, Flower Observatory, for the study of meteor trains, including their heights durations, drifts, spectra, constitution and other physical characteristics 1,000

Grant No. 39—Alexander Biddle, Chairman, The National Economy League, for co-operation in a statewide gathering of facts on the 5635 tax-levying units in Pennsylvania by the Pennsylvania Economic Council. 250

Grant No. 40—Harlan T. Stetson, Cambridge, Mass., for investigation of cosmic-terrestrial relations 2,500

Grant No. 41—Sproul Observatory, to determine the magnitude of stars, utilizing the energy received from them in wave lengths in the red and infra-red parts of the spectrum 1,250

Grant No. 42—Percy Buchanan, Nagoya, Japan, for an investigation of the early linguistic origins of the Japanese language 300

Grant No. 43—Charles A. Kofoid, University of California, for a morphological and physiological investigation of the neuromotor system of the ciliate Protozoa in all of the major types of ciliates with a view to defining the structure and function of such system 1,200

Grant No. 44—Admiral John D. Nares, Monaco, for assistance in the preparation of base charts to be used in the new edition of the General Bathymetric Chart of the Oceans 500

1935, April 19

Grant No. 45—William B. Scott, Princeton University, to complete a monograph on the fossil mammals from the White River beds 1,200

Grant No. 46—Felix E. Schelling, acting for the Modern Language Association of America, for the continuance of the Variorum Edition of Shakespeare 3,000

Grant No. 47—T. T. Chen, Osborn Zoological Laboratory, Yale University, for studies on the mechanism of heredity in unicellular organisms .. 200

Grant No. 48—P. W. Whiting, University of Pennsylvania, for continuation of studies on sex-determination in the parasitic wasp Habrobracon.. 500

Grant No. 49—Francis Bitter, Massachusetts Institute of Technology, for the installation and operation of a coil to give approximately 150,000 œrsteds continuously, and the measurement of magnetic susceptibilities with this coil 1,500

Grant No. 50—Stanley P. Reimann, Lankenau Hospital Research Institute, biological effects of certain pure chemical compounds on proliferation, differentiation and organization of cells, etc 2,000

Grant No. 51—C. C. Little and W. S. Murray, Jackson Memorial Laboratory, Bar Harbor, Maine, for genetical and cytological studies on spontaneous mammary tumors in mice 500

Grant No. 52—Richard McLean Badger, California Institute of Technology, for investigation of the spectra of the simpler polyatomic molecules in the photographic infra-red 800

Grant No. 53—Ernest W. Brown, Yale Observatory, for computing assistance in completing work on the motions of the moon and in particular the motions of the perigee and node, necessary for complete comparison with observation 2,000

Grant No. 54—Arthur J. Dempster, University of Chicago, a precise determination of atomic weights by a new method of positive ray analysis, and the study of isotopic structure. 1,500

Grant No. 55—Ralph E. Cleland, Goucher College, and P. A. Munz, Pomona College, joint taxonomic and cytogenetic survey of Œnothera, subgenus Onagra 1,900

1935, June 19

Grant No. 56—Henry Eyring, Princeton University, theoretical calculation of the absolute rates of chemical reactions using the methods of quantum mechanics and statistical mechanics........ 1,500

Grant No. 57—William D. Harkins, University of Chicago, nuclear reactions caused by high velocity projectiles. 1. Quantitative relations shown by Wilson photographs. 2. Study of artificial radio-activity, especially that produced by neutron bombardment. 3. Scattering of neutrons by protons and other nuclei 1,000

Grant No 58—D. H. Wenrich, University of Pennsylvania, a study of the morphology and life histories of the intestinal protozoa of man ... 500

1935, April, 19

Grant No. 59—Farrington Daniels and B. M. Duggar, University of Wisconsin, (1) Determination of the quantum efficiency in photosynthesis employing monochromatic light, and (2) related thermo-chemical studies 1,000

1935, June 19

Grant No 60—J. W. Beams, University of Virginia. *a.* Acceleration of protons and deuterons to high velocity (several million volts) by a new method developed by the applicant and collaborators. *b.* To study the effects produced by protons and deuterons with energies above three million volts when they collide with nuclei of other atoms, also their scattering in hydrogen... 2,500

Grant No 61—Walker Bleakney, Palmer Physical Laboratory, Princeton, investigation of the isotopic constitution of natural and treated substances with particular emphasis on the study of the relative abundance of isotopes as related to chemistry, geology and biology .. 1,000

Grant No. 62—Lucy Boothroyd Abbe, Cornell University, to determine by means of quantitative and qualitative analysis the histological background for inherited size differences in *Zea mays*. This study is planned to be preliminary to selecting a few characteristic corn dwarf mutants for a developmental study of the plant as a whole and its histology from the embryo and growing point to the mature plant 600

Grant No. 63—J. C. Jensen, Nebraska Wesleyan University, to determine the relation between evaporation from shallow lakes and ponds and the precipitation from local or "heat" thunderstorms. This will also involve the amount of moisture added to the atmosphere by transpiration from growing vegetation 600

Grant No. 64—Samuel Alfred Mitchell, University of Virginia, for the study of of photographs of the "flash spectrum" taken at the total eclipse of the sun on October 21, 1930, on "Tin-Can-Island."..... 1,500

Grant No. 65—Donald F. Jones, Connecticut Agricultural Experiment Station, to study the genetic and cytological basis for atypical growth. 1,000

Grant No. 66—Frank G. Dunnington, California Institute of Technology, for a precision determination of the ratio of Plank's constant to the charge of the electron (*i.e.* of h/e) 2,400*

Grant No. 67—J. Lincoln Cartledge, guest worker at Carnegie Institution of Washington, Department of Genetics, for investigation of the factors which are responsible for increased mutation rate in aged seeds of Datura 600

Grant No. 68—Robley D. Evans, Massachusetts Institute of Technology, for perfection of a new instrument for detecting radium poisoning before the appearance of clinical symptoms; for studying the progress of patients under medical treatment for radium poisoning and for detecting poisonous radioactive contaminants in face creams, tonics, medicinal waters, and patent nostrums 1,000

1935, October 4

Grant No. 69—John R. Murlin, University of Rochester, to study the continuous heat production of small mammals, mouse to dog. Amount of food energy required for growth, in its different phases, from birth to maturity. The difference between the food energy utilized and the heat production is the quotum remaining for growth 500

Grant No. 70—William Ruthrauff Amberson, University of Tennessee, for technical assistance in the study of the physiological significance of the plasma proteins. The research is directed to the study of the functional meaning of the proteins of the blood plasma 1,500

Grant No. 71—H. U. Hall, Ambler, Pa., for the study of the culture of the Bini (Edo) of Benin, Southern Nigeria, with reference particularly to the political and other features of the iconography of the highly developed sculptural art. (Conditional upon obtaining elsewhere the additional aid needed.)........... 2,000

Grant No. 72—L. R. Cleveland, Harvard Medical School, for a study in cytology with particular reference to hypermastigote protozoa.... ... 1,000

Grant No. 73—Murray Barnson Emeneau, Yale University, for an investigation of the Dravidian and Munda languages of India, especially those which, possessing no literatures in written form, have been relatively unexplored in a scientific way................ 2,500

Grant No. 74—Richard M. Field and Assistants, in co-operation with the U. S. Navy and the American Geophysical Union, for a project for determining the submarine structure of the lesser Antiles by geophysi-

* $2,000 of this transferred from Grant No. 6.

cal means, including sonic sounding, gravity determinations, and the recently perfected (1935) submarine seismic method 2,000

1935. December 6

Grant No. 75—Horace G. Richards, New Jersey State Museum, to collect molluscs (especially land) from the Island of Cozumel, off the east coast of the Yucatan peninsula, Mexico. A study of the relationship of this fauna with those of Cuba and the mainland of Mexico and its possible bearing on paleogeography. 200

Grant No. 76—Esther M. Greisheimer (and others), Woman's Medical College of Pennsylvania, for a complete study of the effects of various general and spinal anesthetics on the nervous system, circulatory system, etc. . . . to be followed by the pathological examination of such tissues as the liver, kidney, brain, and heart 2,500

Grant No. 77—George Harrison Shull, Princeton University, for genetical and cytological studies on *Œnothera Lamarckiana* and its derivatives, with a view to resolving the differences of behavior of (*a*) factors linked together because of catenation of the chromosomes; (*b*) those linked in the usual way because of their location at different loci of the same chromosome pair 1,200

Grant No. 78—Harold C. Urey, Columbia University, for investigation of the thermodynamic properties of isotopic compounds of oxygen, nitrogen and hydrogen at low temperatures 2,500

Grant No. 79—H. A. Bethe and Lloyd P. Smith, Cornell University, for studies in (1) the absorption of electrons in matter by the combined effect of scattering and energy loss; and (2) multiple scattering of neutrons 1,500

Grant No. 80—Biological Abstracts (J. R. Schramm, Editor in Chief), to make possible the continued publication of *Biological Abstracts*, which is rendering a vital and essential service to research in biology. 3,500
(An equal sum was granted by the Committee on Publications)

Grant No. 81—C. E. McClung, University of Pennsylvania, for the collection of Orthopteran material for cytological study, in Cordoba, Tecuman and Mendoza and along the river Uruguay in South America. 400

Grant No. 82—Wallace R. Brode, Ohio State University, for the detection of halogens in the chromosphere of the sun through a study of the flash spectrum during the eclipse of the sun of June 19, 1936. 750

Grant No. 83—Frank C. Jordan, Allegheny Observatory, University of Pittsburgh, for the measurement and computation of parallax plates taken with the Thaw telescope of the Allegheny Observatory 1,000

1936, February 7

Grant No. 84—Nabih Faris, Princeton University, for an English translation from a XIV century manuscript of Ihya' 'Ulum al-Din, the magnum opus of abu-Hamid al-Ghazzali (d. 1111), the greatest theologian and philosopher in the history of Islam. For two years work, 1,750 each year. 3,500

Grant No. 85—Ralph B. Cleland and P. A. Munz, Goucher College, and Pomona College, respectively, for the continuation of cytogenetic and taxonomic investigations of Œnothera (sub-genus Onagra). 1,800

Grant No. 86—C. R. Morey, Princeton University, for continuation of the excavation of Antioch-on-the-Orontes in Syria (Publication expenses borne by Princeton University) 5,000

Grant No. 87—M. A. Carriker, Jr., Academy of Natural Sciences, Philadelphia, for the study of bird life of southern Bolivia, to determine (1) the northern extension of the so-called "Patagonian" fauna on

the eastern side of the Andes (snow line to Chaco), (2) the southern extension of the Amazonian fauna, and (3) the extent and character of the northern winter migration of the "Patagonian" fauna east of the Andes.... 2,000

Grant No. 88—Rudolf Hober, University of Pennsylvania, for technical assistance in investigations on the isolated surviving liver of the frog. secretory power of the liver with respect to the bile-pigments and other dyestuffs 1,200

Grant No. 89—Samuel Levine, Research Fellow, University of Pennsylvania, to develop methods for evaluating the Gibbs phase-integral for dense gases, solutions and liquids.... 1,250

Grant No. 90—Glenn L. Jepsen, Princeton University, for continuation of research on the classical "Fort Union Problem" by study of the origin, morphology, and evolution of some of the earliest Tertiary (Paleocene) mammals, and on the stratigraphy of the four horizons in which they occur in the Fort Union formation in Northwestern Wyoming.... 975

1936, April 3

Grant No. 91—Harry Rowe Mimno, Harvard University, for experimental study of the changes in ionization occurring in the upper levels of the earth's atmosphere during the total eclipse of the sun, June 19, 1936. Observations by specially designed radio apparatus.... 1,000

Grant No. 92—J. A. Bearden, The Johns Hopkins University, to study the shapes and wave-lengths of the K and L series x-ray lines of the rare earth elements (atomic numbers 57 to 71).... 2,000

Grant No. 93—Ethel Browne Harvey, Princeton, N. J., for technical assistance in the study of the development of sea urchen eggs without nuclei 1,000

Grant No. 94—Ruth B. Howland, New York University, for experimental studies on the location of the eye-level in egg and early embryo of Drosophila melanogaster.... 150

Grant No. 95—William E Lingelbach, University of Pennsylvania, for a study of Belgian neutrality—its history and interpretation by the Powers in successive crises in European international relations . . 1,400

Grant No. 96—Oliver Justin Lee, Northwestern University, for photography of stars down to the 12th magnitude or fainter with 10½ inch Prismatic Camera. . . . The whole sky from the north pole to declination minus 5° will be recorded on 10″ × 12″ special panchromatic plates giving about 100 square degrees each. This survey will yield a catalogue of all red stars.... 1,000

Grant No. 97—E. A. Culler, University of Illinois, for continuance and extension of work on hearing and conditioning; motor conditioning to sound; measuring electric phenomena of nervous tissue. Work will cover the neural and cortical changes which accompany learning in animals 825

Grant No. 98—Albert Tyler, California Institute of Technology, for investigation of the temperature coefficients of the respiration of unfertilized and fertilized eggs.... 200

The distribution of these grants to the various fields of learning is shown in the following table:

Field	Grants	Amount
Mathematics	1	$ 1,500
Astronomy	10	17,250
Physics	14	21,500
Chemistry	6	8,500
Engineering	2	4,000
Geology, Paleontology, Oceanography	9	11,975
Botany	14	16,150
Zoology	16	13,350
Physiology and medicine	9	11,700
Psychology	2	1,925
Philology	3	6,300
History	1	1,400
Archeology	5	14,850
Ethnology	1	2,000
Political economy	2	6,850
Literature	2	8,000
Biological Abstracts	1	3,500
Total	98	$149,750
Refunded from various grants		2,080=$147,670

The committee has attempted to follow up the work of recipients of grants by requesting a semi-annual report of progress, by publication of some of these reports in *Miscellanea*, and by presentation of some of the more interesting reports at certain sessions of the general meeting or at some of the monthly meetings of the Society. Owing to the crowded character of the program at the general meeting in April it is not possible to make place for many papers from recipients of grants; consequently the committee on research has proposed and the council has approved the holding of an autumn meeting, probably on the Friday and Saturday following Thanksgiving Day, at which meeting reports on work aided by grants from the Penrose Fund would form a principal though not an exclusive part of the program. Such a general autumn meeting is needed not only to acquaint the Society and the public with what is being done by the Society in the promotion of research, but also to afford an additional opportunity for the scattered members of the Society to come together. The National Academy of Sciences, the American Association for the Advancement of Science and several other nation-wide societies hold two or more general meetings each year, and this serves to keep up the active co-operation of members and to stimulate the interest of the general public in the promotion of knowledge. It is proposed that the

American Philosophical Society make the same generous provision for the free entertainment in Philadelphia of non-resident members and invited speakers at this autumn meeting as is now in force at the spring meeting.

The question will certainly arise in the minds of some members, if it does not come to open expression, as to whether the results of researches supported by the Society are worth all that they have cost. The committee has exercised care in the choice of projects to be supported, but undoubtedly some of these have yielded much more valuable results than others. It is in the very nature of research that the results can not be foreseen. In the main the committee has preferred to support projects which are already under way and where the chances of success are great. Many grants have been in the nature of emergency support of work which would have been permanently or temporarily abandoned but for such support. With a single exception grants have not exceeded $5,000, and the average size has been $1,500. The committee believes that with the funds at its disposal it can accomplish more good by making relatively small grants to a large number of persons than by the reverse process. It is true that this method may not make so impressive a show as would the support of a few large projects, but by distributing funds widely there is less risk of making great mistakes, and furthermore if we were to concentrate on a few large projects we would necessarily leave out many fields of research which are represented in the membership of the Society. In further favor of these grants of moderate size is the fact that they fill a gap between the larger grants of the great foundations and the smaller ones of the National Research Council and some other organizations. It has been suggested that our Society should establish research fellowships of a kind similar to those of the National Research Council. Certainly our present plan of making grants for research should not be regarded as permanently fixed. We should continually study to find the best means for promoting knowledge and the committee on research will welcome suggestions as to feasible ways of improving this work of the society.

OBITUARIES

CHARLES ELWOOD MENDENHALL

TODAY the community of science is like an animate being of great and ever increasing complexity, a being each of the parts of which, while fed by the same blood, knows but little of the doings of its fellows. In the dim light of the past we see an era when this great being, not then grown to maturity, was a thing whose every movement was in conscious coordination with every limb, hand and finger of its structure. In these days specialists were few. All knowledge was the domain of the learned. As the years have passed, the interests of the individual investigators have narrowed more and more, so that oft times one finds several men, whose fields of learning go by the same general name, standing of necessity silent in one another's company.

There is much to love in the old way of knowledge; and there is much that is necessary in the new. It is comforting to find in our epoch, however, a few men who can keep themselves in touch with the spirit of the past and who yet can travel the road of the present. Such men can oft times give wise council to the ambition of youth in the blazing of new trails through unchartered forests. Such men can recognize in the scenery which is new some of the pitfalls in other scenery which they and others have known. Such men can act as a stimulant of research and also as a leavening influence in the growth of science. Such men are becoming fewer and fewer in number. Their ranks suffered the loss of one of the most wise and valued of their number when Death called Charles Elwood Mendenhall on August 18, 1935.

The son of a distinguished father who played a prominent part in developing the science of natural philosophy in this country, and in extending its scientific influence abroad, he trod well the path on which his heritage had set him as

science passed from an age which had changed but little in its line of thought from the days of Newton, through the greatest and most rapid evolution which knowledge has ever experienced to the era of today, when concepts which would have seemed but mad fantastic shadows to our fathers, stand now as new rocks upon which our science is built.

Mendenhall was born in Columbus, Ohio, on August 1, 1872, and graduated with a B.S. degree from Rose Polytechnic Institute in 1894. At Johns Hopkins University, where he received a Ph.D. degree in 1898, he was a student of that pioneer of American Physics, H. A. Rowland. Prior to joining the staff at the University of Wisconsin, to whose service he was to devote his life's work, he spent two years at the United States Coast Survey, was an Assistant at the University of Pennsylvania, and instructor in William's College. Entering the University of Wisconsin in 1901, as Assistant Professor, he became Professor in 1905 and Chairman of the Department in 1926, which position he held until his death. During his tenure of office at Wisconsin, he gave freely of his time to public service in various capacities. During the war he was a Major in the Signal Corps in which position, in cooperation with the National Research Council, he did much towards the organization of scientific work in America for militaristic purposes. In this field, his personal experimental dexterity, and knowledge of experimental methods, were of invaluable service in forming judgment as to the practical utility of the various devices which were then under consideration for all sorts of different purposes in connection with the war. Immediately after the war, in 1919, he succeeded Dr. Henry A. Bumstead as a scientific attaché to the American Embassy in London, and coupled with these duties those of the London representative of the Research Information Service

Mendenhall was President of the American Physical Society from 1923 to 1925. He was Vice President of the American Association for the Advancement of Science and Chairman of its Section B in 1929. He was Chairman of the

Division of Physical Sciences of the National Research Council from 1919 to 1920, and a member of the National Research Fellowship Board for almost the whole period of its existence. He was a member of numerous societies including the National Academy of Sciences, the American Philosophical Society, the American Optical Society, and the American Academy of Arts and Sciences. In 1906 he married Dorothy M. Reed, who in addition to being an alumna of several of the country's most noted colleges and universities, was an honorary D.Sc. of Smith's College, and a distinguished authority on medical subjects. The Mendenhall's had two sons, Thomas C., who is a Rhodes Scholar at Oxford, and John T., who is a student of medicine at Harvard University.

Mendenhall's research activities centered around such phenomena as have to do with the surface properties of metals, the photoelectric effect, contact potentials, and the thermal radiation characteristics of metallic surfaces. He was interested in, and contributed much to the development of improved methods of measurement, and particularly of improved sensitive devices for work in connection with the various fields of his interests. Mendenhall was characterized by the breadth of his knowledge, not only in his own subject, but in literature, music, and the arts. He had a special interest in Japanese art, an interest derived from his boyhood days, which were spent with his noted father, T. C. Mendenhall, and his mother, Susan Allen Marple, in Japan. The breadth of his interest and knowledge made him a wise counselor to advanced students, and an invaluable but sympathetic critic. He breathed an atmosphere of calm poise and contentment, and good feeling seemed to permeate the path which he trod. One of his oldest friends, a man of leading prestige in science and in the affairs of the world in general, characterized him as one who was guided by what Socrates called the "inner voice" as consistently as anyone whom he had ever known. He was a man himself keenly sensitive to the humanity in men, and one who had a rare

capacity for divorcing his own personal interests from every problem, scientific or social, which he attacked, so that he gained the confidence of all who were associated with him, and a trust of his fellow men which few could boast.

W. F. G. Swann

LAFAYETTE BENEDICT MENDEL

Although every biological journal is reporting appreciative notices following the death of Lafayette Mendel, it is particularly fitting in the *Proceedings of the American Philosophical Society* that his general interests other than in pure science should be emphasized.

Graduating from Yale at the early age of nineteen years, he had already so established himself as a potential classicist that Professor George Trumbull Ladd told the writer, with considerable acerbity, that science had "stolen" from the classics one of the most promising of young men. Mendel's justification in serving science rather than the classics is fully accounted for by his several hundred papers of biological importance. Thoroughly grounded in science as well as the classics, he brought to his research work a precision that was much needed at that time. Biological chemistry had a distinct tendency to be sloppy, and Mendel introduced, and followed all his life, techniques that were comparable to the meticulous methods of the worker in atomic weights.

His memory was phenomenal. Nearly four decades ago Professor W. O. Atwater was preparing an article for a Government report which was urgently demanded from Washington. Atwater's library was an extraordinarily complete one, but a precise reference to an article was missing. It could not be located in Middletown. It was suggested to Atwater that he call up Mendel by telephone. Mendel, in responding to the telephone, gave instantly the author's name, the title of the paper, the year of publication, and the page (within a very few pages) of that portion of the article where the point at issue was discussed. This phenomenal memory was of good service to him all through his life. No

one had a more complete mental card catalog of the pre-university, university, and subsequent scientific lives of his students than did Mendel. He knew exactly where they were, what they were doing, and with unerring accuracy often predicted their future.

In his association with the American Philosophical Society he exercised his superior spirit of service. Those who were on the Council with him well recall his unusual fund of general information with regard to the various candidates proposed, no matter in what field their intellectual activity. With crystal clarity and well-tempered judgment he would set forth in simple, wholly impartial manner their qualifications for membership.

Scientists bemoan his loss; his colleagues and students no longer can call on that font of information and inspiration, but his loss will be most greatly felt in the whole intellectual and educational life of his university and in his innumerable other scholastic associations.

Francis G. Benedict.

HENRY FAIRFIELD OSBORN *

Our esteemed associate, Henry Fairfield Osborn, member of the American Philosophical Society for nearly fifty years, died suddenly of heart failure at his home in Garrison, New York, in the morning of November 6, 1935. It is a difficult task to express adequately our sorrow in the loss of this warm friend and fellow member. It is also difficult to try to compress into a short space the many-sidedness of his personality and activities, the vast expression of a span of seventy-eight years lived always enthusiastically and fully.

During the course of his long career Professor Osborn was instructor and later professor of comparative anatomy at Princeton University; Da Costa professor of zoology and

* This article is based on tributes by William King Gregory in *The Scientific Monthly*, March, 1933. pp. 284–6; *Natural History*, May–June, 1933, pp. 250–6; *Science*, November 15, 1935, 452–4; *The Scientific Monthly*, December 15, 1935, pp. 566–9; and on a biographic sketch by Florence Milligan in *Bios*, March, 1936, pp 5–24.

dean of the Faculty of Pure Science at Columbia University; founder, curator and honorary curator of the Department of Vertebrate Palæontology at the American Museum of Natural History and president of the Museum for a quarter of a century. He was perhaps the leading spirit in the foundation of the New York Zoölogical Society and served for many years as chairman of its executive committee and as its president. He was the author of some nine hundred-odd papers and volumes on a variety of subjects, some of these merely a few words of comment, some of them monographs running to a million or more words. In addition to these major interests, he found time for many tangential calls and for even unrelated ones, such as his offices in various societies of which he was a member; directorship of several institutions; participation in many movements and causes like restriction of immigration, conservation (particularly of the giant redwood trees and the vanishing wild life of our country), eugenics and discussions of the relations of science and religion. His energy seemed boundless and his youthful enthusiasm continued to the moment of his death.

The Princeton connection and life commenced in 1873 when he entered the University as a freshman. Taking up practical field work in the E. M. Museum of Geology and Archæology immediately on graduation in 1877, he was a member of the palæontological section of the University expeditions to Colorado and Wyoming in 1877 and 1878. The initiation of the plans for these expeditions by Henry Fairfield Osborn and William Berryman Scott, the rigid training submitted to by the young explorers and the success of their exploration are indicative of the enterprising and tenacious spirit which dominated both these distinguished members of our Society. After courses in London under Huxley and Balfour, Osborn was awarded the first E. M. Biological Fellowship at Princeton (1880–1883) and was appointed in 1881 assistant professor of natural science. In 1883 he was promoted to the professorship of comparative anatomy, in which position he remained seven years. Long

after he left Princeton he was influential in many of its projects, such as the building of the new museum of geology and palæontology.

In accepting the call to Columbia University as Da Costa professor of biology, Professor Osborn coincidently entered upon his long and varied connection with the American Museum of Natural History. At Columbia he was the leader in the organization of the zoölogical department, planned the teaching and research work of the department, selected its first officers, organized scientific expeditions and instituted the Columbia Biological Series; during 1894 he served as a trustee of the University press and on the administrative board of publications, suggesting to President Low the idea of a university press at Columbia similar to the Clarendon Press of Oxford University. From 1892 to 1895 he was dean of the Faculty of Pure Science. In 1895 he was selected to give the inaugural course of public lectures on the history of biology; these lectures were later published in book form as "From the Greeks to Darwin."

But it was in the American Museum of Natural History that Professor Osborn found full scope for his powers of expression. The foundation of the Department of Vertebrate Palæontology is considered by some his greatest single achievement and certainly it was to him always a dominating interest. Shortly after he came to the Museum in 1891, with President Jesup's financial support he acquired by purchase the very extensive collection of fossil vertebrates belonging to Professor E. D. Cope. Thereafter, year after year, with the aid of Jacob L. Wortman, W. D. Matthew, Walter Granger, Barnum Brown and others, he conducted an intensive systematic geological and palæontological survey of the western section of the United States, which was later extended to Egypt, India, Mongolia, Burma, Alaska, Mexico, Patagonia and other countries. Thus was amassed what is easily the most extensive collection of fossil vertebrates in the world, while the evolution and dispersal of the vertebrates during the Age of Reptiles and the succeeding Age of Mam-

mals have been revealed through the numerous monographs and articles in Museum publications by Osborn and his staff.

Upon the death of Mr. Jesup Professor Osborn was elected in 1908 president of the American Museum and for twenty-five years he presided easily and securely over a board of trustees that included such preëminent men as J. P. Morgan, Joseph H. Choate, George F. Baker and Cleveland H. Dodge. Great projects begun during Mr. Jesup's administration were loyally carried out and largely completed and he initiated and carried out an even greater number of far-reaching enterprises. He willingly bore the vast and constantly growing burden upon his strong shoulders, a burden that might well have proved too much even for him if he had not discovered the magic of the rule "Divide and Conquer," which he consistently applied. In adhering to this principle he also imposed upon himself a somewhat severe routine: thus in the morning, acting in his capacity as president of the Board of Trustees of the Museum, he sat in the Board Room and transacted the important details of administration; after luncheon he would go to the Department of Vertebrate Palæontology to meet its staff and with them plan the superb exhibit of fossil proboscidea or the spacious architectural effects of the newly-arranged Hall of Fossil Mammals; later in the afternoon he would be closely walled up in his Tower Room, forgetting everything but his beloved fossil elephants. This careful budgetting of his time and physical resources extended into his personal life also, in social interests, exercise and recreation, and accomplished a balance which undoubtedly strengthened his natural ability to concentrate upon the matter immediately before him, whether work, play or rest.

During the twenty-five years of Professor Osborn's administration of the Museum, no fewer than seven immense buildings were added and hundreds of thousands of specimens poured into its numerous departments. Thus the Museum expanded during his presidency to twice its former size, its scientific scope greatly widened and its prestige and influence became world-wide. The seventh building is the New York

State Memorial to Theodore Roosevelt, which Professor Osborn conjured forth with something of Aladdin's magic; as chairman of the Commission appointed to plan this memorial, he gave himself wholeheartedly to the conception of a noble, dignified and beautiful edifice that would perpetuate the memory of a dear friend and fellow naturalist, whose life he held up as a shining example to the youth of America. It is a matter of deep regret that he did not live to enjoy its dedication on January 19, 1936.

In all these great works Professor Osborn was the first to recognize the aid of his co-workers and assistants, though he himself was the brilliantly successful leader of the whole movement. On occasion he disregarded conservative advice and with unshakable faith in the power of his ideals pressed forward with superb courage and persistence until he secured one or another of the major prizes—new buildings, new collections, new explorations—and an ever greater and more far-reaching organization for the diffusion of science and education. Temporary opposition only spurred him on to greater effort and one triumph but opened the way to the next.

Yet he did not aspire to run a one-man show or to build a monument with his name alone inscribed thereon in bronze or granite. He was always a leader, but a leader of men whose names he delighted to honor, companions in arms who shared his triumphs with him and in whose achievements he took the most generous satisfaction. Such, after his own heart, was Roy Chapman Andrews, who carried the flag of the American Museum into the deserts of central Asia and there opened up the astonishing new world of ancient Mongolia. But what inspired Andrews to go there was Professor Osborn's professional prophecy, first uttered in 1899 and 1900, that central Asia would prove to have been the homeland of many families of mammals, families which during the long Age of Mammals sent out colonists to western Europe and western North America and left their fossil bones to fill the great halls of the American Museum of Natural History.

And what enabled Andrews to raise the funds for this scientific invasion of the Gobi Desert was not only his own brilliance and daring but the powerful backing of his beloved chief. Walter Granger and Barnum Brown were equally trusted lieutenants of Professor Osborn—tall, quiet men who move deliberately over great fields and call up long-dead hosts from ancient hunting grounds. In the field and the laboratory, in science and administration, William Diller Matthew was for many years Professor Osborn's first assistant and colleague, succeeding him in the curatorship of the department. I too had the privilege of being associated with him over a long period in his Museum and Columbia University work and was for thirty-five years honored by his confidence and friendship. He took pride in the fact that so many of his colleagues had been his graduate students at Columbia University. And great was his joy also when among the younger men of other universities he discovered one like George Gaylord Simpson to whom he felt he could confidently entrust the huge palæontological investigations of the next generation.

It was therefore with affectionate pride and loyalty that when he resigned the presidency of the Museum, in January, 1933, he was greeted as its Master Builder, in all phases of its expansion.

Fortunately, it was not because of failing power that Professor Osborn retired from the administrative office of the Museum, but that he might have more leisure to devote to the completion of the series of monographic studies for which he has long been justly famous among the palæontologists of the world. The Titanothere Monograph, published in 1929 as the result of twenty years' work, numbers 953 pages, with 797 text figures and 236 plates. The monograph on the Proboscidea, on which he was engaged at the time of his death, dwarfs the Titanothere work; Volume I is in press and will soon be released, and Volume II will be published in its unfinished state by the Museum. His fifty-eight years of "research, observation and publication" left a deposit of some 940 published communications, ranging from brief

articles to these voluminous monographs; he dictated tens of thousands of letters and wrote by hand hundreds of others. In the many organizations in the development of which he was actively interested he was seldom long unheard. The most important of his scientific writings were in the field of vertebrate palæontology, but the principles of evolution, the prehistory of man, the biography of great naturalists, eugenics, and educational methods and ideals were subjects always in or near the front of his teeming mind. Among his scientific volumes "The Age of Mammals," "Men of the Old Stone Age" and "The Origin and Evolution of Life" continue to hold a deservedly high place in the estimation of his admiring public.

His truly colossal output has been acclaimed by the learned world, both at home and abroad. The Royal Society of London welcomed him as a foreign member, as did a long list of other leading scientific societies in Europe, China, India, Persia, Mexico, and South America. To him were awarded many gold medals and coveted prizes: the Darwin Medal of the Royal Society, the Wollaston Medal of the Geological Society of London, the Albert Gaudry Medal of the Geological Society of France, the Roosevelt Medal of Honor, among others. The oldest universities in Europe vied with the universities of his own country in bestowing upon him their honorary degrees.

It is too soon to attempt a final appraisal of Professor Osborn's contributions to science, but certainly it is safe to say that among them may be included the following:

(1) his initial studies on the origin of the corpus callosum of the mammalian brain;
(2) his memoir on the Mesozoic mammals;
(3) his numerous contributions to the study of the evolution of mammalian molar teeth to and beyond the tri-tubercular type;
(4) his many important papers and monographs on the fossil rhinoceroses, titanotheres, horses and proboscideans;
(5) his great text-book, "The Age of Mammals."

With regard to the theory of evolution, his outstanding principles, or laws as he called them, include the following:

(1) the law of *continental and local adaptive radiation;*
(2) the law of *homoplasy*, or parallel but independent evolution in related lines of descent;
(3) the law of *tetraplasy*, whereby evolution results not from the operation of single causes but is the resultant of forces from four principal directions (external environment, internal environment, heredity, selection);
(4) the law of *alloiometry*, or adaptive modification of dimensions of the skull, feet or other parts, arising independently in different lines of descent;
(5) the law of *rectigradation*, or *aristogenesis;* that is, the gradual appearance during long ages of new structural units of adaptive value, predetermined in the germ plasm and in their initial stages independent of natural selection;
(6) the law of *polyphyly; i.e.*, the normal occurrence of many related lines of descent, derived eventually from a common stock but coexisting throughout great periods of time.

We see in his early study on the fœtal membranes of the opossum and other marsupials signs of his ability to choose subjects of strategic importance. The same is true of his studies on the origin of the corpus callosum of the mammalian brain; in his rather extended paper on the principal fiber tracts of the brains of amphibians he opened up a line of investigation which has been carried on by, among others, Professor C. J. Herrick, who gladly acknowledges the importance of Osborn's pioneer studies. In fact, between 1883 and 1887 comparative neurology may be said to have been his principal subject and, with the assistance of Dr. Oliver S. Strong, he planned to write a general work on comparative neurology.

Gradually, however, his papers in vertebrate palæontology became more numerous and after another extended residence in England he completed his memoir on Mesozoic Mammals

(1888), which again demonstrated his ability to choose a subject of major importance and to extract from it far-reaching results; for it was the Mesozoic mammals that carried back the history of the mammalian molar teeth to a very distant date, when the triangular or so-called tritubercular molar crown was in its initial stages. He therefore endorsed Professor Cope's theory of the origin of the tritubercular molar, adding many original evidences and observations of his own and early developing an ingenious system of naming the principal cusps of the upper and lower molars, which system has since been adopted by the palæontologists of the world. While giving every due credit to Cope, he proceeded to apply his own nomenclature in detail to the complex molar patterns of ungulates and showed how, with this tritubercular key, as he called it, one could unlock and open up the most complicated molar patterns, analyzing their parts and reading the history of the group.

It is obviously impossible to enumerate here the many radiating interests that filled the ever-busy lifetime of Professor Osborn, but it is pertinent to refer to his relations with the American Philosophical Society. He was elected to membership in the year 1887 and the mutually valued connection continued unbroken for almost half a century, until his death last November. Professor Osborn ranked this organization among the most important of his society affiliations and, on its part, the Society continually expressed its high opinion of him, by electing him to office, by seeking his advice, by requesting papers for its meetings. He served several terms as councilor, covering the years 1905–1914 and 1917–1920; six years as vice-president, from 1922 to 1928; several times as a delegate to and from the Society, notably in 1909 at the centenary celebration of Charles Darwin's birth at Cambridge University and in 1927 as representative of the Cambridge Philosophical Society at the Bicentenary Celebration of the American Philosophical Society; as a member of different committees, the most important of which was the Committee on Development appointed in 1928 in

connection with the plan for a new building and expansion of the Society. At that time his advice was sought by President Dercum, who said that he felt there were few men in the country as qualified as Professor Osborn to advise as to the best course to pursue just then.

Among the honors the Society offered Professor Osborn would have been his election to the presidency, to succeed Professor Scott for a term of seven years that would have covered the critical period of expansion and removal to the proposed new building, as well as the celebration of the Society's two hundredth anniversary. Professor Osborn felt obliged to decline the nomination because of the pressure of his scientific and institutional work; it was never possible for him to have a merely nominal connection of any kind—the acceptance of office always meant the contribution of his enthusiastic interest and activity.

He was deeply interested in the quality of the membership of the Society and with the thought in mind of maintaining its high standard he gave close attention to the matter of nominations and elections. He greatly enjoyed his meetings and correspondence with Dr. W. W. Keen during Dr. Keen's presidency of the Society. Undoubtedly his closest friend for more than half a century was Professor William B. Scott; on the latter's retirement as president of the Society, it was a joy to Professor Osborn to arrange the painting and financing of Professor Scott's portrait by Robert Vonnoh, the artist who had painted President Keen.

Most of Professor Osborn's addresses before the Society were invited. The first was presented in 1887, the last in 1934—about twenty in all, four of which were on the subject of his thirty-five-year research, the Proboscidea. In the Bicentenary year, 1927, he was especially asked to deliver the one evening address; he chose human ancestry for a subject, with the title, "Recent Discoveries relating to the Origin and Antiquity of Man."

Now what manner of man was this, who governed so easily and maintained such a multitude of contacts and

could yet find time to produce a prodigious mass of scientific and educational writings? How did he come by his power and serenity, his dignity, his benevolence, his steadfastness, his good humor, his quiet friendliness? Let it be admitted that even the lowest human intelligence is too complex to be accounted for historically and that the growth of each being is a unique integration of actions and reactions to hereditary, physiological and environmental stimuli which it is difficult or impossible to untangle; nevertheless, there are abundant historical data which at least indicate some of the leading influences to which Henry Fairfield Osborn in the course of his own development reacted as he did.

First of all, he was extremely fortunate in his heritage. On both sides were ancestors of sterling integrity, intelligence and good judgment, some of whom distinguished themselves. His mother's family seems to have lived for generations in Fairfield, Connecticut. Records of this little town of long ago describe in detail costly and elaborate costumes at gay functions in well-appointed homes—certainly these were not the Increase Mather type of Puritan. The Sturgeses were people of property, participants in its charming social and intellectual life. There were patriots in the line, notably Major Nathan Gold of Revolutionary fame, "a Pious and Worthy Magistrate"; one ancestor, the Reverend Ebenezer Pemberton, a prominent divine, was a founder of the College of New Jersey (Princeton University); his grandfather, Jonathan Sturges, a highly successful and respected merchant in New York, was vice-president of its Chamber of Commerce and a director of the Illinois Central Railroad among his many activities. Jonathan Sturges' daughter Virginia, mother of Henry Fairfield Osborn, combined in herself the outstanding qualities of her forbears, with her gentle forcefulness and religious nature.

The early American Osborns were not so definitely localized; they are recorded in several Massachusetts towns, particularly in Salem, but when we narrow down to William Osborn, grandfather of Henry Fairfield, we find that he also was a man of property. It was probably choice, therefore,

which ended the formal school life of his son William Henry at the age of thirteen. Thenceforth the boy apparently ordered his own life and the story of his success is that of a so-called self-made man: entering an East Indian trading house in Boston, he was sent as their representative to Manila, where he was soon in business for himself; on his return to America he allied himself with the incomplete Illinois Central Railroad and in time became its long-term president, engineering it through the panic of 1857 to security and expansion into one of the important lines of the country and at the same time building up a considerable personal fortune. But though a shrewd and indomitable business man by profession, William Henry Osborn's taste ran to literature and art and he showed discrimination in a good collection of books and paintings; with high disregard for convenience he chose a difficult mountain-site for a home because a spring of pure water attracted him; he cultivated fine friendships and had wide acquaintance with many notables of his time.

This, then, is the hereditary background of Henry Fairfield Osborn, son of William Henry and Virginia Reed (Sturges) Osborn, and his environment was no less distinguished. He was born August 8, 1857, at his mother's old home in Fairfield and therefrom acquired part of his given name, but his life-time home was in the Hudson River Highlands. The family residence on a slope of the mountain took its name from its growth, "Wing-and-Wing." Later another residence arose on the very top of the mountain, the "Castle Rock" which has become so inseparably connected with the name of Henry Fairfield Osborn. The elder Osborn evidently had a sincere admiration for the grand manner in nature, in art and architecture, and the exact spot upon which the tower of Castle Rock is built was chosen with great care. From a wide stone platform there one can look outward upon a view of astonishing magnitude, sweep and beauty, with the broad curving Hudson River beneath, the granite mass of Storm King beyond and, just opposite, the imposing walls of West Point. In the home of wealth and good taste the boy Fair-

field was reared, with the companionship of an older sister and two younger brothers. In the surrounding woods and countryside the young nature lover found a world and the nascent scientist opened up his first geological field.

In his early educational life Osborn recalled the rigid school discipline of the Columbia Grammar School in New York under the two Bacon brothers and the genial atmosphere of his Greek studies under Dr. Howard Crosby. His preparation for Princeton was under Mr. Lyons, a fine old Fairfield pedagogue who in 1869 established his Collegiate Institute in New York. Osborn was too young to recognize the force of these influences but he soon acknowledged the inspiration of the teachers of his older periods. In his college and post-graduate life he had the good fortune to come under great masters: President James McCosh of Princeton schooled him, he tells us, "in the bypaths of classic and modern philosophy and logic" which eventually fitted him "for philosophical generalization in the too often stern and dry facts of palæontology"; Arnold Guyot, Swiss geologist at Princeton, encouraged his first original researches in palæontology; William H. Welch impressed him by the breadth and thoroughness of biological research and his presentation of the cumulative progress of anatomy; in England Francis M. Balfour, as an example of creative and educative ability, and Thomas Henry Huxley, by his encyclopædic learning and exalted sense of public duty, left their impress. The young Osborn carried the essence of these influences into his own teaching and endeavored to project particularly the methods by which he had benefitted in their laboratories, notably following in technique and outline the Huxleyan general method of biological instruction and adopting Balfour's personal "student-with-student" attitude. The Guyot influence was the directing force in his exploration and the philosophical bias of Doctor McCosh is to be observed in most of his writings. In England in the winter of 1879–1880 Osborn found himself at the very source of many of the influences which he had felt in his home across the ocean: some interesting friendships

were begun and contacts established at this time, notably with the Huxley and Darwin families and Edward B. Poulton, and in the collaboration with Francis Galton in his studies on the visualizing faculty. Professor Osborn's ancestry and upbringing predisposed him to appreciate and respond to the potent and ennobling ideals of the great Victorians and this tendency was strengthened at the Princeton of 1877, which was largely an outpost of British culture under President McCosh and Americans of English and Scottish descent.

Something more than all this, however, contributed to his triumphal drive, leading him over more than half a century to wider and wider activities of organization, construction and administration and to scientific investigation, publication and education on a vast scale. Part of that something was his tireless and highly successful wife, Lucretia Perry Osborn, who was his most ardent admirer and energetic partner and probably the most compelling influence in his life. It was she who helped to make Castle Rock not only a brilliant background for his personality but also a quiet retreat in which his creative work could be produced without interruption or intrusion. It was she who sustained his spirit during periods of opposition and discouragement and her death in 1930 deprived him of a powerful support and of the companionship so necessary to one of his temperament. At the same time perhaps it intensified his passionate belief in the reality both of "creative evolution" and of the most essential features of modern Christianity. These beliefs he had derived from the days of his youth, and in all his writings on evolution, education and religion they are set forth with clearness and conviction. Doubtless his philosophy will be evaluated differently by those who view it from opposite poles, but it is clearly incumbent upon a student of his life to set forth his philosophy along with his science.

William King Gregory

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A STUDY OF THE OLDEST KNOWN VERTEBRATES, ASTRASPIS AND ERIPTYCHIUS

WILLIAM L. BRYANT

(*Read April 25, 1936*)

ABSTRACT

The discovery of a vertebrate fauna in the Harding Sandstone, of middle Ordovician age, was announced by Walcott more than forty years ago. Two genera described at that time remain the oldest known vertebrate fossils. Yet they never have been adequately studied and their systematic position has always been uncertain.

A histological study of the exoskeleton of these primitive fish-like creatures reveals that they are members of the Order *Heterostraci* in a comparatively low state of development. They agree with the other members of that Order in the absence of cell spaces in the exoskeleton. *Eriptychius* is closely, and *Astraspis* more distantly, related to the *Drepanaspidæ*. The minute structure of the superficial denticles in the exoskeleton of *Astraspis* differs from that in any other of the *Agnatha*, in that it is composed of concentric laminæ knitted together by fibres and capped by a thick layer of a hard amorphous substance resembling enamel. The body form of these animals is still unknown.

INTRODUCTION

MORE than forty years ago, in a paper which he characterized as "preliminary notes," the late Charles D. Walcott announced the discovery of an Ordovician vertebrate fauna at Canyon City, Colorado.[1] Two species described at that time stand as the most ancient vertebrate fossils yet found in America. Moreover, with the possible exception of certain minute and problematical fossils from the Ordovician of Europe, they are still the oldest known vertebrate remains in the world. Nevertheless, these fossils have never been adequately studied and their systematic position is still uncertain.

One reason for this lies in the fragmentary condition of the fossils. In spite of their local abundance they occur only as detached scales and broken pieces of larger plates, scattered through the matrix in which they are imbedded. Only one

[1] Walcott, Charles D., "Preliminary Notes on the Discovery of a Vertebrate Fauna in Silurian (Ordovician) Strata." *Bull. Geol. Soc. of Amer.*, 3, 1892

large and fairly complete dermal plate has yet been found. This, unfortunately, is preserved merely as a sandstone mould of the external surface of the plate.

The present studies are based upon collections kindly made for the writer by Professor J. Harlan Johnson of the Colorado School of Mines. Many of the specimens are from the Old Harding Quarry at Canyon City. Others were obtained from St. John's Quarry on the north side of the Arkansas River, west of Canyon City. Here they were collected from two horizons about eight feet apart and some thirty to forty feet above the base of the Harding Sandstone. Still other specimens were obtained from unrecorded Harding localities on the western side of the Sawatch Range and near Taylor Park. The United States National Museum also loaned me a suite of specimens including the large plate described in a footnote to Walcott's paper. For these favors I desire to express my sincere thanks.

Historical

Walcott established three genera of supposed fishes, each represented by a single species. The first of these, *Dictyorhabdis priscus*, he tentatively identified as "the ossified chordal sheath of a fish allied to the recent *Chimæra*." Some years later Bashford Dean [1] restudied this form and concluded that the supposed chordal sheaths could have nothing to do with vertebrates but were probably only fragments of the shells of molluscs, possibly Cephalopods. Paleontologists have generally concurred in this opinion and probably no one nowadays believes *Dictyorhabdus* to be a vertebrate fossil. Thin sections show the lamellar structure of shells and only confirm Dean's opinion.

Two other forms described by Walcott as *Astraspis desiderata* and *Eriptychius americanus* are of undoubted vertebrate origin.

The latter species was based entirely upon detached scales. Deceived by their superficial resemblance to the scales of

[1] Dean, Bashford, "Chimæroid Fishes and Their Development." Carnegie Institution of Washington. Publication No. 32. 1906.

Crossopterygian fishes, Walcott placed *Eriptychius* in the family *Holoptychidæ*.

There has been no attempt to distinguish the remains of *Eriptychius* from those of *Astraspis* in the histological studies made upon the vertebrates of the Canyon City bone bed. These two species, which actually differ greatly from each other in microscopic structure, have thus been confused. Because of this fact and of general reluctance to admit the presence of ganoid fishes in deposits as early as the Ordovician, *Eriptychius* has been dropped from the literature. No discussion of this form has appeared in recent years.

The form described by Walcott as *Astraspis desiderata* was originally based upon exceedingly fragmentary dermal plates. Adopting the classification proposed by Traquair in 1888 Walcott placed *Astraspis* in the family *Asterolepidæ* among the ganoid fishes of the sub-order *Placodermata*. Shortly after the presentation of his paper and before it was published, a large and nearly complete plate was found at Canyon City and described in a footnote to Walcott's paper as a portion of the head carapace of *Astraspis*. Comparing the tessellated longitudinal ridges of this plate with the rows of tubercles on the cephalic shield of *Thyestes*, he remarks that, "the portion of the carapace preserved and its appearance suggests the Cephalaspidian fishes of the Silurian of Russia, while the separate plates and Astræ-form tubercles foreshadow the *Asterolepidæ* of the Lower Devonian."

Jaekel, who examined thin sections of the fossils, discussed their microscopic structure in a note appended to Walcott's paper. He found dentine tubules in the superficial tubercles of certain specimens and indications of cell spaces in the underlying tissue. He concluded that "the occurrence of true osteoblasts distinguishes these hard parts from those of the *Elasmobranchii* and relegates them to the division of the ganoids. Enamel could not be found in the specimens studied. On account of this and by the strikingly distinct lamination in the dentine tubercles, the hard parts investigated indicated a low state of development." He also con-

cluded that "the pteraspids and acanthodians dominating in the uppermost Silurian are absent from this fauna."

It should be remarked that although Jaekel did not say so, all of his figures illustrating the microscopic structure of the fossils are of *Eriptychius* with the exception of Fig. 3 of Pl. 5, which seems to be a fragmentary tubercle of *Astraspis*.

In the discussion following the reading of Walcott's paper, Cope doubted the occurrence of ganoids at so low a horizon, and in a review published shortly thereafter he suggested that these forms were more likely *Agnatha* than true fishes.[1]

Some years later Valliant[2] confirmed Jaekel's discovery of bone lacunæ in the Harding fossils and agreed with him that the remains were those of true fishes.

The next important discussion of these fish remains is to be found in Eastman's paper on the fossil fish collections of the United States National Museum.[3] He pictured for the first time the "compound" shield of *Astraspis* which superficially at least is subdivided into polygonal areas, and pointing out that it lacked the orbits and other prominences characteristic of Cephalaspid head shields, compared it instead with the dorso-median shield of *Psammosteus* and *Drepanaspis*. However, because of the somewhat peculiar shape of the shield and of the presence of a median and two parallel lateral ridges traversing the shield in a longitudinal direction, Eastman thought it necessary to place *Astraspis* in an independent family, closely allied to the *Drepanaspidæ*. In Eastman's paper no mention is made of *Eriptychius*.

In 1921 Woodward[4] stated that microscope sections of *Astraspis* had been made in the British Museum and seemed

[1] Cope, E. D., "The Vertebrate Fauna of Ordovician of Colorado," *Amer. Natur.*, XXVII, 1893.

[2] Valliant, Leon, "Sur la Présence du Tissue Osseux Chez Certains Poissons des Terrains Paléozoiques de Canyon City, Colorado," *C. R. Acad. Sci. Paris*, CXXXIV, 1902.

[3] Eastman, Charles R., "Fossil Fishes in the Collection of the United States National Museum," *Proc. U. S. Nat. Mus.*, 52, No. 2177, 1917.

[4] Woodward, Arthur S., "Visit to the Gallery of Fossil Fishes, British Museum of Natural History," *Proc. Geologists Assoc.*, XXXII, Part 3, 1921.

to show that they belonged to a primitive Ostracoderm related to *Cephalaspis*. In the second edition of the English translation of Zittel's *Text Book of Palæontology*, Woodward places *Astraspis* among the *Osteostraci* and provisionally in the family *Ateleaspidæ*, conceding however that it may belong to a distinct family.

Stensio, in his work on the Cephalaspids of Spitzbergen,[1] remarks that "at present there are no facts known which justify the establishment of new families either for *Psammosteus* or for *Astraspis*, but both these genera may very well be assigned to the family *Drepanaspidae*," and accordingly, later in the same work he denies the presence of cell-spaces in the exoskeleton of *Astraspis*.

In a paper on the Morphology of the *Heterostraci*, Stetson [2] discussed the microscopic structure of specimens collected from the bone bed of Canyon City. Like Jaekel, he did not distinguish between the species studied but from his description it is apparent that he had under observation specimens both of *Astraspis* and *Eriptychius*. Stetson observed fine, lacunæ-like spots in the basal layer of some specimens but stated that conditions are unfavorable for the preservation of fine microscopic structure. Comparing the Astraspid tubercles with those of Drepanaspids and Psammosteids, he concludes that "taking everything into consideration we may assume that these animals are true members of the foregoing groups."

Stetson also discovered waterworn scales of *Thelodus* on weathered surfaces of the sandstone. Such scales are rare, but certain detached Astraspid tubercles of the mushroom type, with constricted neck and median basal perforation, when broken away from the underlying tissue, and somewhat water-worn and stained, present a striking superficial resemblance to *Thelodus* scales. In histological structure, however, they are quite different.

[1] Stensio, Erik A:son, "The Downtonian and Devonian Vertebrates of Spitzbergen. Part I, Family *Cephalaspidæ*." *Skrifter om Svalbard og Nordishavet*, Nr. 12, 1927.

[2] Stetson, H. C., "Studies on the Morphology of the *Heterostraci*," *Jour. of Geol.*, XXXIX, No. 6, 1931.

As conodonts are generally admitted to be of ichthyic origin it is proper to refer here to the presence of a peculiar conodont assembly found closely associated with the usual fish remains. First discovered by Kirk[1] who figured many forms, more than forty species from the Canyon City bone bed have been described by Branson and Mehl in a recent paper.[2] A curious feature of these conodonts lies in the fact that they show basal attachment to fragments of supporting plates which, according to Kirk, are identical in appearance and composition with the fish plates of the Harding. In fact, Kirk was convinced that these toothlike objects were parts of the same animals. The present writer does not agree with this interpretation. These conodonts are said by Branson and Mehl to exhibit certain features which they regard as primitive, including a peculiar "fibrous" structure and lack of the ordinary basal excavation.

The Ordovician age of the Harding Sandstone, although questioned by some writers, has been thoroughly established by the work of Darton, Kirk, Behr, Johnson, and Branson and Mehl.[3] The Harding Sandstone is now known to underlie Ordovician strata over an area of several thousands of square miles in Colorado and Wyoming. Its exact position is still uncertain, but it is doubtless within the Middle Ordovician. The studies of Branson and Mehl based on the conodonts indicate that the Harding should be placed near the bottom of the Middle Ordovician.

[1] Kirk, Stuart R., "Conodonts Associated With the Ordovician Fish Fauna of Colorado. A Preliminary Note," *Amer. Jour. Sci.*, XVIII, 1929.

[2] Branson, E. B. and Mehl, M. G , "Conodont Studies Number 1," University of Missouri Studies, VIII, No. 1, 1933.

[3] Darton, N. H., "Fish Remains in Ordovician Rocks in Big Horn Mountains, Wyoming, With Resume of Ordovician Geology of the Northwest," *Bull. Geol. Soc. Amer.*, XVII, 1906.

Kirk, Edwin, "The Harding Sandstone of Colorado," *Amer. Jour. Sci.*, XX, Fifth Series, No. 120. 1930.

Behr, C. H. and Johnson, J. H., "Ordovician and Devonian Fish Horizons in Colorado," *Amer. Jour. Sci.*, XXV, Fifth Series, No. 150, 1933.

Branson, E. B. and Mehl, M. G , "Conodont Studies Number 1," *University of Missouri Studies*, VIII, No 1. 1933.

Material and Methods

Lithologically, the Harding Sandstone consists of a varicolored succession of shales, sandstones and impure quartzites. The sandstones are usually saccharoidal and friable with an arenaceous or calcareous matrix. In certain areas the Harding is partly represented by glauconitic sands containing phosphatic nodules. Cross bedding, ripple marks and annelid borings testify to its deposition in shallow waters.

The vertebrate fossils consist of scales and more or less rolled and waterworn fragments of dermal plates rarely attaining a length of more than 10 mm. and usually much less. When unstained, these fossils have a peculiar blueish white color with the lustre of semi-opal. While the sculpture of the plates is often clean-cut and brilliant and the microscopic structure well preserved, in other specimens there is evidence of corrosion, both internal and external. The dentine tubercles and underlying tissues of *Eriptychius* are now so soft that they may be easily scratched by a copper needle, but the enamel-like caps on the tubercles of *Astraspis* have, apparently unaltered, retained their original hardness.

The thin sections illustrated in this paper were cut from the red sandstones, sometimes mottled with yellow found in the quarries in or near Canyon City. In some places the fish fragments have been washed up into heaps among the sands and comprise nearly fifty per cent of the rock. Owing to the friable nature of the rock and the comparative softness of the fish fossils, it is not easy to make satisfactory thin sections. After sawing a slice of the rock it was first soaked in turpentine, then in very dilute canada balsam and afterwards heated until quite hard according to the method proposed by David Forbes.[1] The slice was then ground thin in the usual way. Previous to the hardening process, some of the sections were stained by methylene blue. More than fifty thin sections were prepared in this way.

[1] Forbes, David, "On the Preparation of Rock Sections for Microscopic Examination," *Mon. Microsc. Jour.* I, 1869.

Description of the Fossils

Astraspis desiderata Walcott

Pls. I–VII

1892. *Astraspis desiderata* Walcott. Bull. Geol. Soc. Amer., III, p. 153, Pl. III, Figs. 6–14; Pl. IV, Figs. 1–4; Pl. V, Fig. 3.

This species is known by a unique median dorsal shield and by innumerable fragments of others and of detached scales. The dorsal shield, known only by its impression in the matrix, is shown enlarged on Pl. I. It measures 72 mm. in length and 50 mm. in greatest width. Although none of the actual tissue is preserved, several important inferences may be drawn from this specimen. Its bi-lateral symmetry shows that it was a median plate and that little of the original contour is missing. The plate has been somewhat crushed, and from the absence of continuous fracture lines one may deduce that the shield was more or less flexible. It was composed of a mosaic of polygonal tuberculated plates. In certain places the individual tesseræ have been pushed up or depressed, intact. We may thus assume that the division of the plate into polygonal areas was not caused by mere superficial grooves as in the Cephalic shield of *Cephalaspis*, but that the shield of *Astraspis* was actually compound as recognized by Walcott, being formed by a large number of discrete polygonal tesseræ. There is no evidence of overlapped areas on the individual tesseræ of this specimen. In outline, the shield is reminiscent of the median-dorsal plate of certain Arthrodires. A conspicuous feature of the fossil is found in the sharp ridges that traverse the anterior half of the plate in a longitudinal direction.

The ridges on the shield of *Astraspis* are approximately equi-spaced. They consist of a median and four subparallel lateral ridges, the outermost of which are close to and parallel with the lateral margins. The median ridge is the longest, being 43 mm. in length. Those next to it on either side are the shortest, measuring only about 28 mm. in length. The

two outermost ridges are apparently almost as long as the median. These ridges are composed of a large number of crested tesseræ arranged in linear order.

Along the lateral margins of the plate, the tesseræ are oblong and nearly rectangular. Elsewhere they vary considerably in shape and size. The ornamentation of the smaller tesseræ usually consists of a large median stellate tubercle around which are grouped a large number of much smaller, but similar, tubercles. Some, however, have two large tubercles and at least one of the larger tesseræ bears on its surface six of the larger tubercles arranged in two rows. On the other hand, the oblong tesseræ along the lateral margins of the plate have no large median tubercles but are studded with the smaller ones. In outer form those tesseræ in which the median tubercle is absent very much resemble the tesseræ in the head of *Ateleaspis tesselata* Traquair, from the Downtonian beds of Scotland. In microscopic structure, however, they are very different.

In its present condition the shield of *Astraspis* is gently arched from side to side and from front to rear. The anterior margin is not well preserved but seems to have been nearly straight with a short median projection. The shield is widest near the anterior margin and gradually tapers posteriorly for about two thirds of its length. From thence it rapidly tapers, terminating in a pointed median process.

From the foregoing account, it is apparent that the shield of *Astraspis* differs greatly both in form and in the presence of symmetrically disposed ridges from the ovoid dorsal and ventral plates of *Psammosteus* and *Drepanaspis*. It must be acknowledged, however, that there is a decided and striking resemblance in the ornamentation of the individual tesseræ of the Astraspid plate to that on the polygonal tesseræ found in the outer layer of the shield of *Psammosteus taylori*. In each case this ornamentation consists of stellate tubercles, often with smooth apices. Of these the central tubercle is usually much larger than the others which are closely grouped around it.

Detached polygonal tesseræ of the type found in the shield of *Astraspis* occur in great numbers in the Canyon City bone bed. Some of them are illustrated in Walcott's paper (Pl. III, Figs. 4, 8, 10, 12; Pl. IV, Fig. 1). Of these, Fig. 8 on Pl. III resembles the oblong tesseræ on the lateral margins of the shield where enlarged tubercles do not occur. These tesseræ or little plates are often quite thick in vertical section. The basal or visceral surfaces of the plates are uniformly perforated by a great number of vertical canals (Pl. V, Fig. 2).

The Astraspid plate or scale is composed of three layers—a well developed basal layer with numerous vertical canals, a middle layer with meandering vascular canals and an upper layer, confined to the superficial tubercles (Pl. II, Fig. 3). Two types of Astraspid tubercles occur in the bone bed. Their microscopic structure is identical and leads to the conclusion that there must have been a variation in form of the tubercles in different areas of the body covering.

The first type is that found on the large shield and consists of round, stellate tubercles with pointed apices from which sharply cut grooves and ridges radiate outwards to the margin (Pl. II, Fig. 2). Sometimes the apices of these tubercles are quite smooth, probably as the result of wear. Usually the tubercles are constricted below the crown so that in side view they have a mushroom or stud-like outline with overhanging sculptured cap (Pl. III, Fig. 2; Pl. IV, Fig. 1).

The second type of Astraspid tubercle is ovate in outline with low, rounded crown. The margins are crenulated. The sculpture consists of grooves radiating towards the widest end and deepest at the periphery, recalling the sculpture on the scales of the ganoid fish *Cheirolepis* (Pl. II, Fig. 1).

The tubercles of *Astraspis* are capped by a thick, hard, transparent, enamel-like substance, which however, is neither typical enamel nor ganoine. This glassy substance overhangs the underlying tissue. At the summit of the tubercle it is often thick enough to constitute about a third of the depth of the tubercle. The sculpture of the tubercle is confined

entirely to this enamel-like substance and does not penetrate to the tissue beneath (Pl. III, Fig. 1; Pl. IV, Fig. 1).

The glassy coating has a hardness of about five and one half in Moh's scale and according to the Becke test has a much higher index of refraction than that of the adjoining tissue beneath. It dissolves easily in hydrochloric acid. When examined in thin sections under the microscope it shows no evidence of prismatic or laminar structure and in polarized light behaves as an amorphous substance, remaining dark in all positions between crossed nicols. In these features it differs radically from any type of enamel or ganoine with which I am familiar. Obviously, it can hardly be a replacement of the original tissue by any other amorphous mineral substance. A horizontal slice through the tip of the enamel cap often takes the form of an eight-pointed star, due to the sharply cut grooves and ridges (Pl. V, Fig. 3).

The tissue underlying the enamel cap and composing the remainder of the tubercle contains neither cell spaces nor dentine tubules, and consequently is neither bone nor dentine. It is a dense but transparent substance, built up of numerous distinct concentric laminæ. These are everywhere penetrated by a system of minute subparallel fibres resembling the fibres of Sharpey. They radiate from a pulp-like cavity when such exists, otherwise from a median area in the tubercle, and extend outwards to the periphery (Pl. III, Figs. 1, 2; Pl. IV, Fig. 2). In stained sections they have the appearance of exceedingly minute tubulets.

A median or basal cavity communicating with the underlying vascular system is often found in these tubercles. Such cavities resemble in some respects the pulp cavities of ordinary dentine tubercles. Lateral canals sometimes lead out from them and ascend to the surface between the tubercles. These lateral canals are in connection with others arising from the vascular canals below, and which also open at the surface. Probably together they compose the mucous canal system (Pl. IV, Fig. 1).

In those tubercles showing no median or basal cavity there

is strong evidence that such a cavity formerly existed but has been filled by successive deposits of fibrous tissue from within.

The concentric lamination of the Astraspid tubercle is well shown in horizontal sections (Pl. VII, Fig. 2). Such sections cut below the enamel cap are doubly refractive. When viewed in polarized light with crossed nicols they show a black cross.

The middle layer of the Astraspid plate is composed of a dense substance containing neither cell spaces nor dentine tubules. It, therefore, falls within the definition of "aspedin," a name proposed by Gross[1] to distinguish the tissue characteristic of the *Heterostraci*. The vascular canals in this layer are comparatively few in number, with remarkably thick walls (Pl. II, Fig. 3). The canals vary in size and shape according to the direction in which the section is cut. Also, in different specimens there is considerable variation in the number and size of the sinuses and in the thickness of the walls enclosing them. Lateral by-passes connecting the canals are comparatively infrequent. In horizontal sections the canals appear to be more evenly distributed, with numerous vertical tubes and few lateral by-passes.

In some specimens one finds an approach to a subdivision of the middle layer into cancellous and reticular portions, in that the upper vascular canals are narrow with thick walls, while below they are much wider with thinner walls. Such examples greatly resemble corresponding portions in the dermal skeleton of *Psammosteus*.

As stated above, some of the canals of the middle layer send out branches which have their orifices on the surface of the plate between the tubercles. While, as seems probable, these may be mucous canals, there is no apparent uniformity in their distribution, although they seem to occur in groups. Such a group is illustrated on Pl. V, Fig. 1. Here a horizontal section has been cut through the bases of a number of tubercles and shows the orifices of the supposed mucous canals.

[1] Gross, Walter. "Die Fische des Mittleren Old Red Sud-Livlands," *Geol. und Pal. Abhdl.*, Bd. 18, Heft 2. 1930. P. 13.

The aspedin of the middle layer is laid down in concentric laminæ surrounding the vascular canals (Pl. VI, Figs. 1, 2). On the borders of these canals one often observes laminæ filled with fine fibres radiating inwards from the cavities (Pl. VI, Fig. 1).

While true cell spaces do not occur in *Astraspis* one sometimes finds in thin sections numerous small cavities some of which resemble bone lacunæ. They vary greatly in size and shape and some even seem to have outrunners like tubules. They have no definite arrangement in respect to the laminæ and are even found in the tubercles. Sometimes these cavities are greatly elongated as though produced by boring (Pl. VII, Fig. 1). When examined under high power they seem to resolve into groups of minute vermiform cavities. Usually they occur only in plates that show other clear evidence of decay or corrosion, such as is seen on Pl. V, Fig. 1 of Walcott's paper. The figure in that instance illustrates a specimen of *Eriptychius* in which such cavities are also sometimes found. As they seldom or never occur in well preserved plates, it must be concluded that they are the result of post mortem corrosion, and that true cell spaces are entirely lacking.

The basal layer in the exoskeleton of *Astraspis* is well developed and very thick. It is composed of numerous fine and distinct laminæ laid down parallel to the base. As the inner surface of the Astraspid tessera is often undulating, the basal laminæ are not always horizontal but follow the lower contour of the plate (Pl. II, Fig. 3). The basal layer is penetrated by vertical canals the orifices of which are on the inner surface. These canals seldom communicate with each other, but pass upward into the vascular system of the middle layer. Sometimes the basal layer is greatly developed and extends upward at the expense of the middle layer, which it partially supplants.

Fibres resembling the fibres of Sharpey are often observed in the basal layer. They arise at the visceral surface and pass vertically upwards in parallel groups.

The basal layer of *Astraspis*, like the middle layer, is doubly refractive. In polarized light the laminæ, and sometimes the fibres, stand out distinctly.

We may now inquire if the information obtained as the result of the foregoing morphological and histological study leads to any conclusions regarding the relationship of *Astraspis* to other early vertebrates.

We must at once admit that these fragmentary remains tell us little as to the body form of the animal. Perhaps we may fairly assume from the dorsal (?) shield that at least the anterior parts were defended by exoskeletal plates arranged after the fashion of the *Heterostraci*, with a prominent median dorsal plate, and probably with a corresponding one on the ventral side of the body. I think we may also conclude from the great abundance of polygonal tesseræ found detached, that certain areas between the dorsal and ventral plates were covered by polygonal scutes similar to those found in the family *Drepanaspidæ*. The ornamentation of these plates also superficially resembles that in some members of that family. Furthermore, we have found that the plates of *Astraspis* are composed of aspedin, a substance found only in the *Heterostraci* and that they are formed of three layers, the basal and middle layers somewhat resembling those in the *Drepanaspidæ*. But there the resemblance ends. The shape of the median plate is quite different from those found in the *Drepanaspidæ* and while the superficial layer of the armor in some members of the *Drepanaspidæ* is marked off into polygonal areas, in *Astraspis* the plate at least appears to be composed of individual tesseræ, more or less fused together. The appearance of the shield supports this view as does the structure of the comparatively thick and massive tesseræ found in the sandstone.

The structure of the tubercles studding the surface of Astraspid plates is totally unlike anything found in any member of the *Heterostraci*, or for that matter in any other ostracoderm. Instead of the dentine tubercles and ridges of the *Heterostraci*, we find tubercles composed of laminæ

knitted together by fibres, lacking either in cell spaces or dentine tubules and protected by a heavy coating of a peculiar type of enamel.

The morphological and histological structure of the exoskeleton in *Astraspis* thus differs in many important features from that found in any other of the *Heterostraci*, and these features collectively are certainly of family value. Yet the presence of bone lacking in cell spaces points to membership in that order. In my opinion, *Astraspis*, for the present, should be included within the *Heterostraci* and assigned to the family *Astraspidæ* as proposed by Eastman in 1917.

Eriptychius americanus Walcott

Pls. VIII–XIII

1892. *Eriptychius americanus* Walcott. Bull. Geol. Soc. Amer., III, p. 153, Pl. IV, Figs. 5–11; Pl. V, Figs. 1, 2, 4.

Our knowledge of this creature is founded almost entirely upon its detached scales. These occur in immense numbers in the Harding bone bed. However, the head and forepart of the trunk of the animal must have been protected by plates of considerable size. Fragments of such plates are not infrequently found but none of them are sufficiently complete to afford an indication of their shape. They are ornamented by coarse broken ridges, apparently running nearly straight in a fore and aft direction. Such a fragment is illustrated on Pl. VIII, Fig. 2. In this case the plate is partially concealed by what appears to be a portion of the exoskeleton of an undescribed fish.

The scales vary considerably in shape. Usually they are broader than long and exhibit wide areas of overlap (Pl. VIII, Fig. 1; Pl. IX, Figs. 2, 4). This is an unusual feature in the *Heterostraci*. They are ornamented with short subparallel dentine ridges which tend to break up into low-crowned tubercles. Usually the longer ridges are pointed

at the posterior end of the scales and may project as spinelets. Often smaller ridges or tubercles are intercallated between the coarser rows. On some scales the tubercles and ridges are extremely irregular in shape with deeply indented margins (Pl. IX, Figs. 1, 3). Intermediate stages are found between all these forms. No doubt therefore, the character of the ornamentation varied considerably in different areas of the exoskeleton, agreeing in that respect with the *Drepanaspidæ*.

Between the ridges on the scales of *Eriptychius* one may see the openings of numerous pores arranged in linear fashion. Where the ridges lie fairly close together their sides are indented around these openings, giving the ridges a crimped appearance (Pl. VIII, Fig. 1). I assume these pores to be the outlets of the mucous canals.

When a vertical section of one of these scales is examined under the microscope it is found to be built up of three layers (Pl. IX, Fig. 5). The uppermost layer is confined to the superficial dentine ridges and tubercles. It is composed of transparent concentric lamellæ which are penetrated and bound together by minute parallel fibres, disposed at right angles to the laminæ much as they are in *Astraspis*. Beneath each ridge or tubercle lies a median pulp-like cavity from which arise rather coarse dentine tubules. These branch as they ascend. The outermost branchlets extend to the extreme periphery of the ridge where they open on the surface as there is no superficial layer of enamel (Pl. XI, Figs. 1, 2). As Jaekel pointed out, the concentric laminæ do not run in continuous curves but are slightly deflected inwards between the dentine tubules (Pl. XI, Fig. 1).

The pulp-like cavities communicate with the underlying vascular canals by wide channels and also often send off lateral canals which ascend to the surface between the ridges (Pl. X, Fig. 1; Pl. XII, Fig. 2). Several pulp cavities are often found beneath the longer ridges, but sometimes they are fused into one (Pl. X, Fig. 3; Pl. XIII, Figs. 1, 2). In horizontal sections through the dentine ridges the fibrous structure of the concentric laminæ and the arrangement of

the pulp cavities and dentine tubules are often well shown (Pl. X, Fig. 2). Viewed in polarized light the dentine ridges are weakly doubly refractive, apparent only in rather thick sections. There is no banding of the upper layer nor any evident transition into any type of enamel.

The middle layer of the dermal exoskeleton of *Eriptychius* consists of lamellar tissue without cell spaces. It is perforated by large vascular canals forming a spongy labyrinth (Pl. X, Fig. 1; Pl. XII, Fig. 2; Pl. XIII, Fig. 2). The sinuses are irregular in shape and size and there is no distinct division into cancellous and reticular portions as in the Pteraspids. In this respect the middle layer of *Eriptychius* closely resembles that of the Drepanaspids but is even more generalized than in the Devonian forms. A great number of branches ascend from the vascular canals, both to the cavities beneath the dentine ridges and to the surface between the ridges or tubercles (Pl. X, Fig. 1; Pl. XII, Fig. 2). The external surface of the *Eriptychius* scale is pitted with such openings, and a horizontal section through the uppermost portion of the middle layer shows a uniform network of rather closely spaced vertical canals (Pl. XII, Fig. 1). Towards the margins of the scales the middle layer may be quite dense, with comparatively few vessels (Pl. IX, Fig. 5).

The basal layer of the dermal skeleton of *Eriptychius* is well developed. It consists of aspedin or tissue lacking cell spaces built up of horizontal laminæ (Pl. IX, Fig. 5). It is penetrated by many wide vertical canals which rarely communicate with each other. Sometimes the basal layer is greatly expanded vertically at the expense of the middle layer which is correspondingly reduced (Pl. X, Fig. 3). In such cases one sometimes observes a vertical canal passing completely through the exoskeleton from the lower to the upper surface. However, these vertical canals usually lead into the more complicated vascular system of the middle layer.

In certain thin sections one finds abundant evidence of corrosion, not only on the walls of canals and pulp cavities,

but in minute pittings throughout the tissue. These sometimes simulate cell spaces as remarked in the description of *Astraspis*.

One may question whether more than one species of *Eriptychius* occurs in the Harding bone bed. Certainly one finds great variety of form in the surface denticles, a variation whose extremes seem to be bridged by intermediate forms. This is paralleled by a certain amount of variation in the microscopic structure of the exoskeleton. On the other hand, we find some variation of the microscopic structure of certain layers in different areas of the same plate. At the most, these variations are only of specific value.

The histological structure of the exoskeleton in *Eriptychius* indicates a very close relationship to the Devonian *Drepanaspidæ*. Indeed there seems to be no valid reason for excluding it from that family. Some thin sections made from scales of *Eriptychius* might easily be mistaken for those of *Psammosteus meandrinus* Ag. The chief difference between them lies in the greater development of the basal layer in *Eriptychius* and in a complete lack of any sub-division of the middle layer into cancellous and reticular portions. Also, in vertical sections of *Eriptychius* cut in a longitudinal direction in respect to the dentine ridges, the vascular canals are not drawn out horizontally to the extent that they are in *Psammosteus*.

The building up of the dentine ridges in successive laminæ, tied together by fibres penetrating the various layers, is another feature that appears to distinguish *Eriptychius* from the remainder of the Drepanaspids. It is paralleled in the tubercles of *Astraspis* and may well be considered a primitive feature.

Conclusion

All available evidence indicates that both *Astraspis* and *Eriptychius* are members of the Order *Heterostraci* in a comparatively low state of development. They agree with

the other members of the Order in the absence of cell spaces in the exoskeleton. *Eriptychius* is closely, and *Astraspis* more distantly, related to the *Drepanaspidæ*. The minute structure of the superficial tubercles in the exoskeleton of *Astraspis* differs from that in any known animal. Unfortunately, little or nothing is known as to the body form of these ancient creatures. Pending new discoveries we must be content with the knowledge that among the *Heterostraci* is found the oldest known vertebrate fauna.

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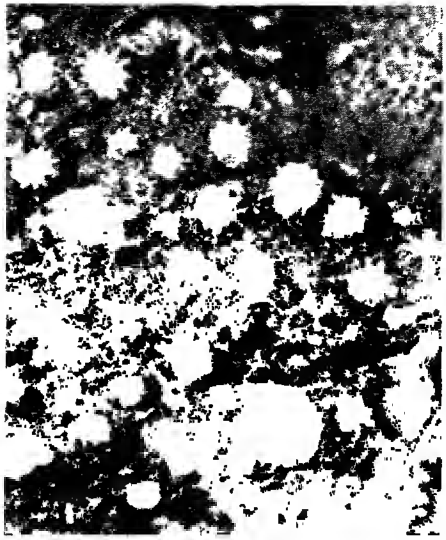
PLATE I

Astraspis desiderata Walcott

Compound median dorsal (?) plate, preserved as an impression in the matrix of the outer surface. × 1½



3

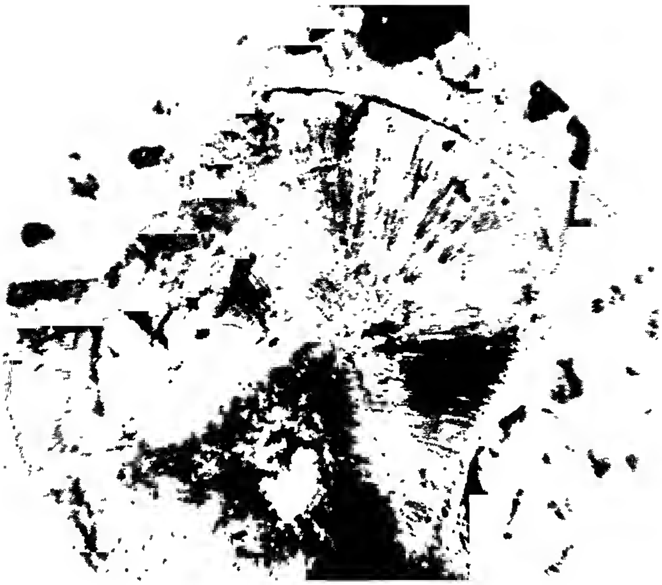
Astraspis desiderata Walcott

FIG. 1. Tubercles of the low-crowned, oval type. × 12.

FIG. 2. Stellate tubercles with pointed crowns. × 12.

FIG. 3. Vertical section through tessera. The basal layer is well developed. Two tubercles with the characteristic thick coating of glassy, structureless enamel are shown in this specimen. × 45.

PLATE III



1

2

Astraspis desiderata Walcott

FIG. 1. Vertical section through tubercle showing sculptural enamel crown surmounting the fibrous lamellar tissue composing the remainder of the tubercle. The large triangular black area near the base is a pulp-like cavity. × 170.

FIG. 2. Vertical section through tubercle. Note the thick layer of enamel, and fibrous tissue beneath. × 160.

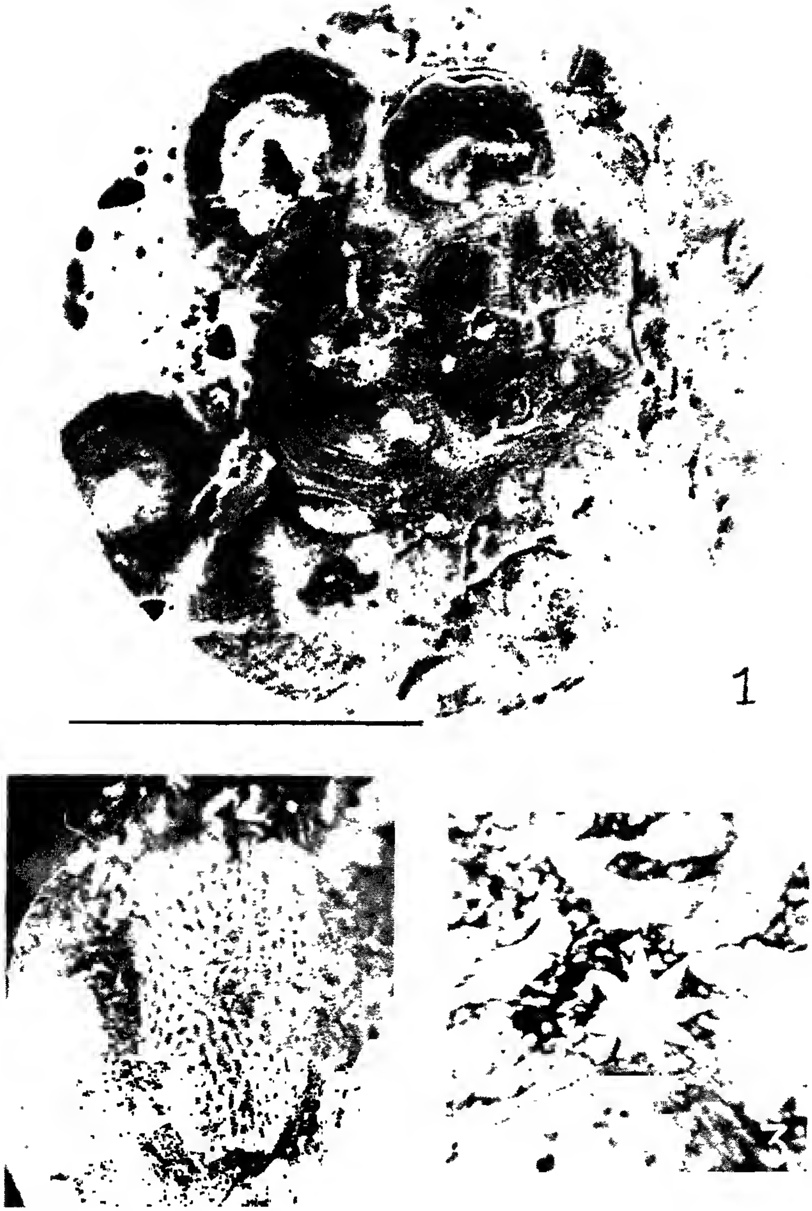
PLATE IV

Astraspis desiderata Walcott

FIG. 1. Vertical section through two tubercles showing pulp-like cavities. The enamel crown of the tubercle on the left of the illustration is cut in a direction transverse to the sculptured ridges. × 105.

FIG. 2. Vertical section through a tubercle of the low-crowned, oval type. The fibrous lamellar structure beneath the enamel-like cap is well shown. × 216.

PLATE V



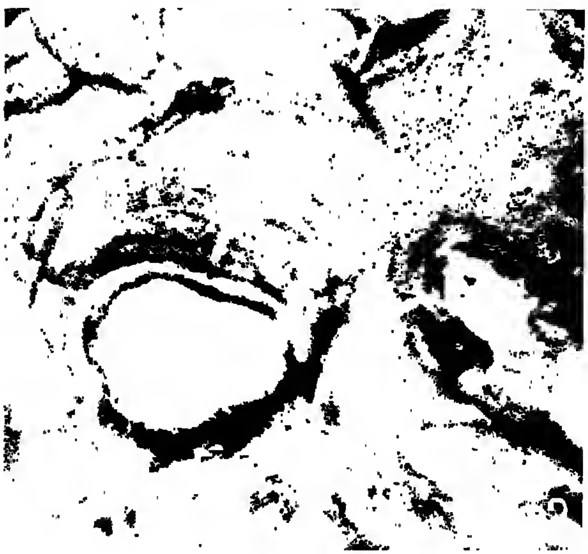
Astraspis desiderata Walcott

FIG. 1. Horizontal section through the base of a number of tubercles, showing the orifices of a group of supposed mucous canals. × 55.

FIG. 2. Scale or tessera in visceral view, showing network of perpendicular canals. × 7

FIG. 3. Horizontal section through tip of stellate tubercle, showing sharply cut sculpture of the enamel. × 65.

PLATE VI

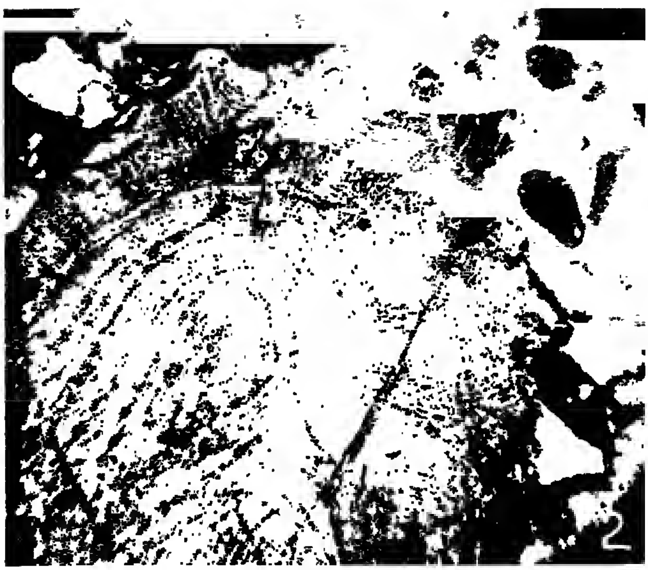


Astraspis desiderata Walcott

FIG. 1. Horizontal section through middle layer of plate. In upper right may be seen concentric fibrous laminæ. × 200.

FIG. 2. Obliquely horizontal section through middle layer, showing concentric lamination around vascular canal. Note the absence of cell spaces in the illustrations on this plate. × 200.

PLATE VII

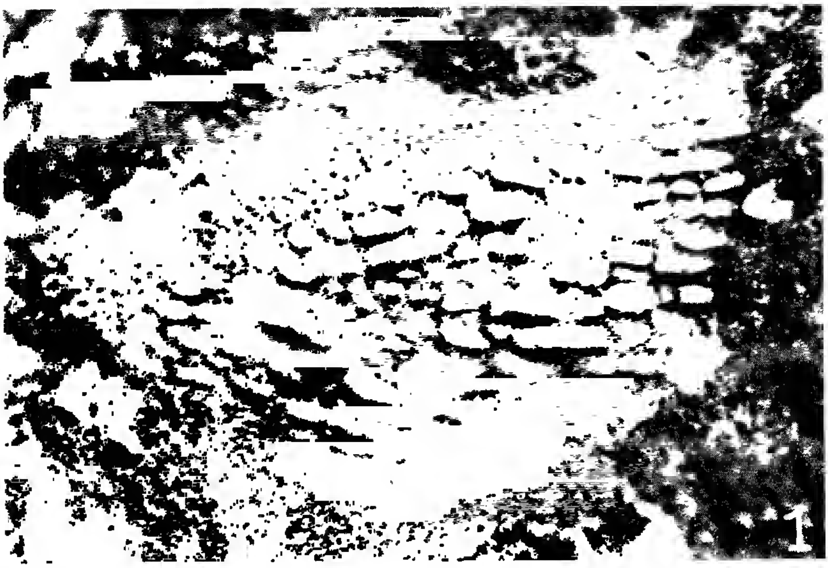


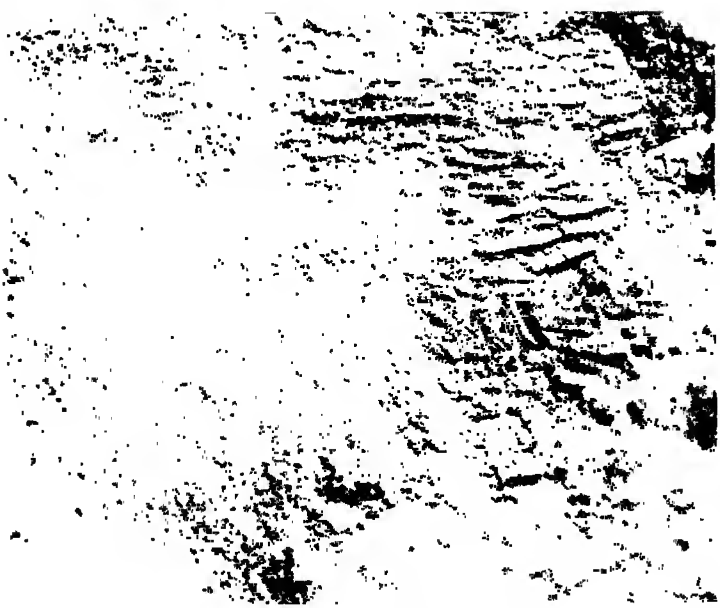
Astraspis desiderata Walcott

FIG. 1. Horizontal section through middle layer of plate, showing evidence of corrosion or post-mortem decay. × 190.

FIG. 2. Obliquely horizontal section through tubercle, showing fibrous structure of lamina. The sculptured margins of the enamel-like cap project on the right

PLATE VIII

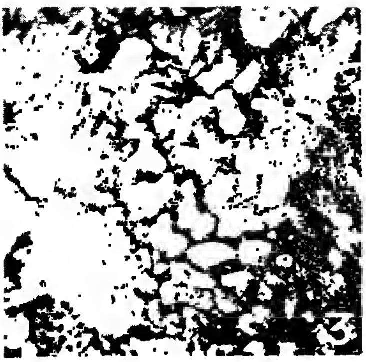


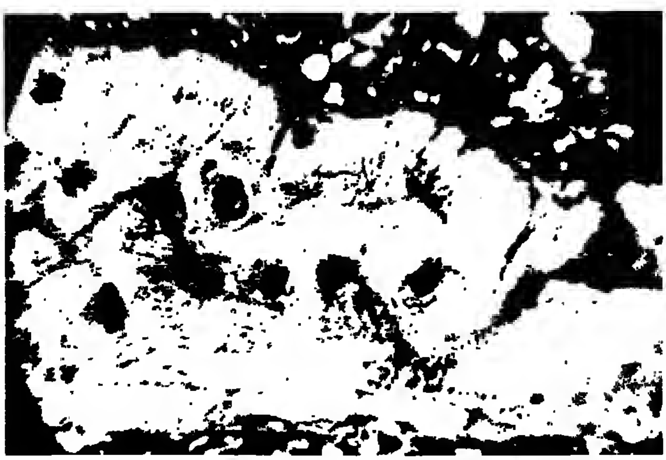


Eriptychius americanus Walcott

FIG. 1. Scale showing area of overlap and the orifices of supposed mucous canals. × 12.

FIG. 2. Fragment of plate partially overlain by shagreen-like tissue of an undescribed species. × 6.





Eriptychius americanus Walcott

FIG. 1. Indented ridges and tubercles of scale fragment. × 6

FIG. 2. Scale showing area of overlap. × 6.

FIG. 3. Indented tubercles of scale fragment. × 8.

FIG. 4. Scale showing area of overlap. × 6.

FIG. 5. Vertical section through scale near margin. × 93

PLATE X

Eriptychius americanus Walcott

FIG. 1. Vertical section through middle and superficial layers of scale. Note lamellar structure and absence of cell spaces. × 120.

FIG. 2. Horizontal section through two dentine ridges. The section is cut near the base of the ridge. The concentric laminae are well shown. The uppermost parts of the pulp cavities are seen as dark spots in the median line. × 95.

FIG. 3. Vertical section of scale cut in a longitudinal direction. The basal layer with its wide perpendicular canals is greatly expanded at the expense of the middle layer. × 72.

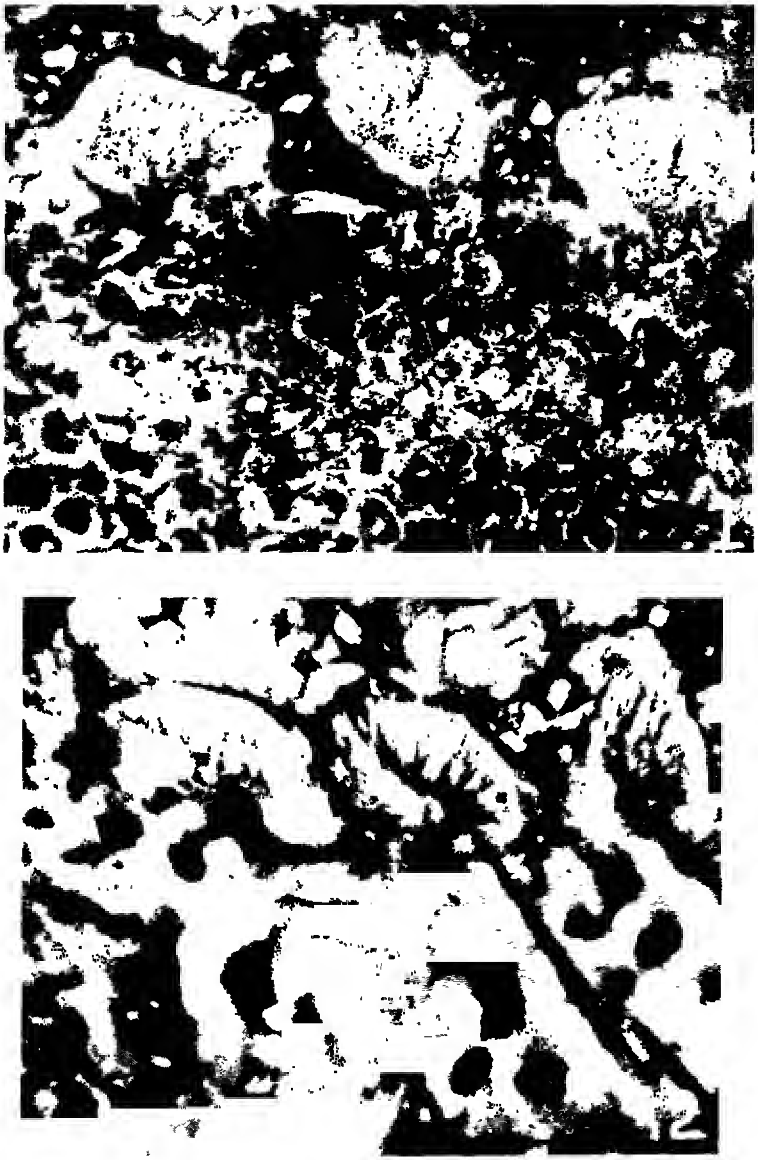
PLATE XI

Eriptychius americanus Walcott

Fig. 1. Vertical section through dentine tubercle, showing the concentric lamination. × 200.

Fig. 2. Vertical section through large dentine tubercle, showing branching tubules. × 85.

PLATE XII



Eriptychius americanus Walcott

FIG. 1. Obliquely horizontal section through upper portion of scale. × 60.
FIG. 2. Vertical section through middle and superficial layer of scale. × 120.

PLATE XIII

Eriptychius americanus Walcott

FIG. 1. Vertical section through scale. × 65.
FIG. 2. Vertical section through upper portion of scale. × 100.

HABITUS FACTORS IN THE SKELETON OF FOSSIL AND RECENT MAMMALS

WILLIAM K. GREGORY

Read April 25, 1930

ABSTRACT

Palæontological and comparative data show that skeletal parts are adapted through the ages to new functions. Each stage is a composite resulting from the interplay of habitus and heritage factors. Habitus characters may converge, as in the case of two different orders of animals, or may run parallel, as in two animals of the same order, and they always overlie and partly or completely conceal heritage characters.

The mammalian backbone is selected to illustrate the effect of stresses imposed upon the skeleton throughout its evolution and individual development. In the pre-fishes, or ostracoderms, the backbone consisted of a notochord, arcs and which in reaction to the stress of muscular movement the bony centra of the teleost fishes were finally produced. This backbone was a mere appendage of the head, with no connection with either the pectoral or the pelvic girdle.

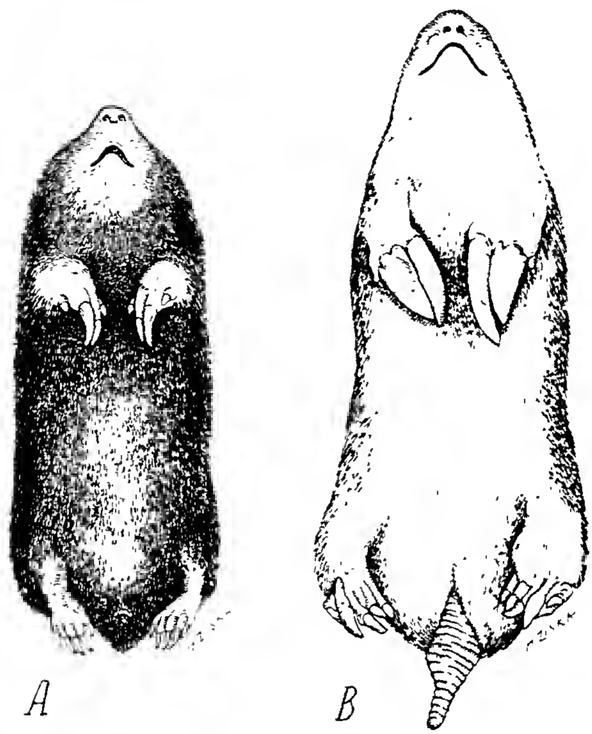
In the crossopterygian fishes the paired fins began to serve as paddles, which in the early amphibians were used gradually to raise the body in progression on land. After the freeing of the pectoral girdle from the back of the skull, it served as a U-shaped sling or cradle for the fore part of the body. The pelvis, originating in the ventral musculature and growing dorsad, eventually gained a connection with the backbone by way of the sacral ribs. Thus originated a sort of combined suspension and cantilever bridge, consisting of pectoral and pelvic girdles as the piers between which the bridge of skull and backbone is suspended: this is the basis of the mammalian condition. Several ways in which large and heavy skulls are supported or suspended from the backbone are considered and also the drawbridge action of the fore part of the body upon the hip joint.

These principles are illustrated in a series of skeletons mounted by Mr. S. H. Chubb.

To palæontologists no proof is needed that in some way or other structural patterns are closely adjusted to their owner's environment and ways of life, and for the moment it is not necessary to make any embarrassing choice between the older theories associated with the names of Buffon, Lamarck and Darwin, and the newer theory of preadaptation defended with much ingenuity by Cuenot and Davenport.

Figure 1 gives a striking example of similar habitus combined with different ordinal heritage, the form at the right belonging to the order Polyprotodontia of the subclass Marsupialia, that on the left belonging to the order Insectivora

of the subclass Placentalia. Thus convergence may be defined as similar habitus with different ordinal heritage; parallelism, on the other hand, as the resemblance in habitus between members of different families of the same order.



A B

Fig. 1. Similar habitus with different ordinal heritage.
A. Chrysochloris, order Insectivora, subclass Placentalia;
B. Notoryctes, order Polyprotodontia, subclass Marsupialia.

In general, habitus characters tend to conceal the ordinal or class relationships of any given form, while heritage characters when discovered reveal its class and ordinal relationships. Experience shows that part of the habitus of a remote ancestor is transmitted to its descendants and, under changed conditions, it becomes part of the heritage of the descendants. Thus a habitus character becomes a heritage character after a change of function.[1]

[1] Gregory, William K., "Locomotive Adaptations in Fishes Illustrating 'Habitus' and 'Heritage'," *Ann. N. Y. Acad. Sci.*, Feb. 10, 1913, pp. 267, 268; "On the 'Habitus' and 'Heritage' of Caenolestes," *Journ. Mammalogy*, vol. 3, No. 2, May, 1922, pp. 106-114.

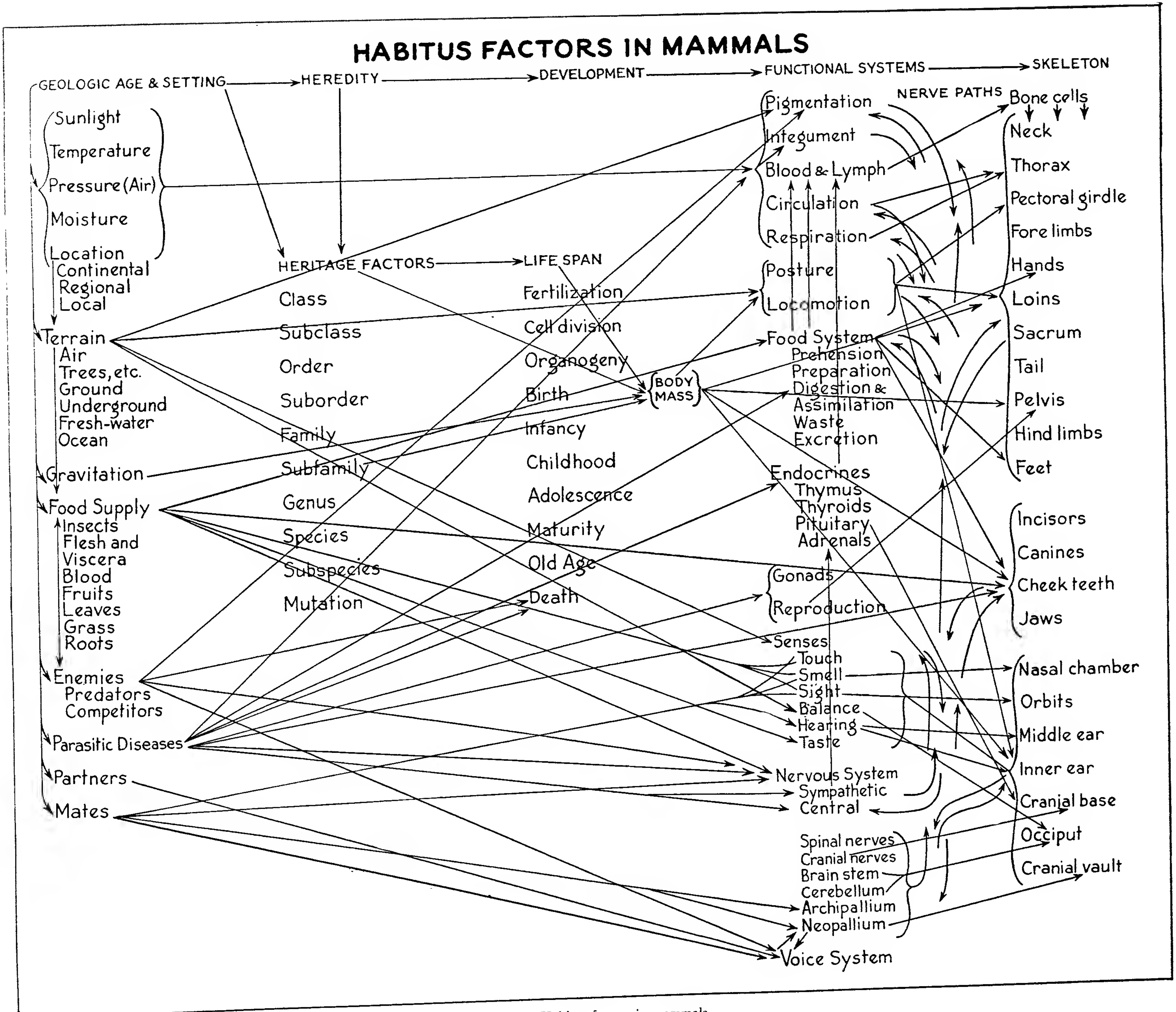


FIG. 2. Habitus factors in mammals.

Some of the outstanding factors in the habitus of any given form of skeleton are indicated in figure 2. No doubt the interactions of such factors are even more complex than those here suggested. One of the fundamental conditions of any given habitus is the geologic age and environmental setting. The peculiar habitus of the woolly mammoth, for example, appears only in Quaternary times for the simple reason that it represents a very advanced and relatively recent stage of adjustment and that neither the hereditary nor the environmental stages that led up to it date below the upper and middle Tertiary horizons.

The specific, generic, family, subordinal, ordinal and class heritages of any given type limit in decreasing degree the next steps open to it, but we have not time to illustrate this far-reaching principle.

Heritage factors and the length of the life-span both enter into the magnitude of body mass, and this in turn has diversified influences upon every part of the skeleton. Palæontology and comparative anatomy likewise afford abundant evidence that in the long run the skeletal patterns are influenced directly by almost every change in the normal morphology and reactions of all the other organ systems of the body, and indirectly by changes in the physical and biotic environments. For example, the gradual introduction of grasses on the western plains in early Tertiary times encouraged the evolution of many lines of grass-eating animals with long-crowned complex cheek teeth.

Although such facts and principles are familiar in a general way to all palæontologists, there is still great need of the study of fossil teeth and skeletons from a functional viewpoint. Let us consider therefore a few of the ways in which the mammalian backbone has reacted to the stresses imposed by the interactions of body weight, muscular action and the thrusts coming from the skull and from the limbs by way of the girdles.

The wide adaptive radiation of the mammalian backbone can best be appreciated in the light of even a brief and cursory

review of the earlier stages of the evolution of the backbone in premammalian vertebrates. It will be recalled that the earliest vertebrates, which are known as ostracoderms, did not have any backbone in the strict sense, but merely a notochord or dorsal axial rod. This structure, however it arose, reacted against the stresses set up by the metameric muscles or myomeres on the sides of the body so as to produce lateral undulations and drive the large head forward in search of food.

The living *Amphioxus*, which may be a highly specialized and secondarily small-headed, naked derivative of some of the ostracoderms, shows us the notochord in a dominant condition before it became restricted by central rings.

The backbone in its typical vertebrate form is illustrated in this skeleton of a teleost fish (Fig. 3). Here the bony

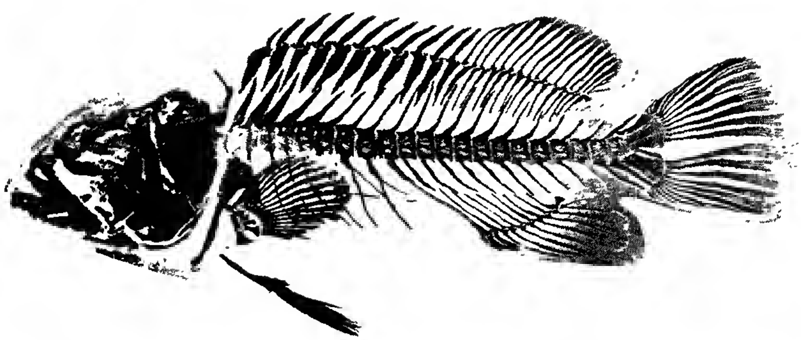


Fig. 3. Skeleton of a typical teleost fish (*Promicrops itaiara*).

centra have already replaced the notochord, at least in the adult condition. These centra serve on one hand to provide a jointed column to which the muscles are attached, through the ribs, neural and haemal arches; on the other hand, the backbone, by the cooperation of all its parts, forms a series of arches which protect from strangulation the delicate parts

of the spinal nerves and central nervous system. These primary functions of the vertebrate backbone, acquired in the watery medium, became indispensable parts of the heritage of the land-living vertebrates, including the mammals.

At first the backbone was chiefly an appendage of the head. The pectoral girdle was originally the posterior boundary of the branchial chamber and as such it was attached to the skull. Its relations to the fins were a later development.

The pelvic girdle originated as a base for the pelvic fins and for long ages had no connection with the backbone.

It was only in the stage of the lobe-finned or crossopterygian fishes of late Palæozoic times, which all recent evidence suggests are at least nearly related to the direct ancestors of the land-living animals, that the paired paddles began to serve even in an incipient way as paired limbs.

By the time of the earliest amphibians the fundamental plan of the five-toed limbs was already evolved, but the backbone shows relatively little advance beyond that of the fish.

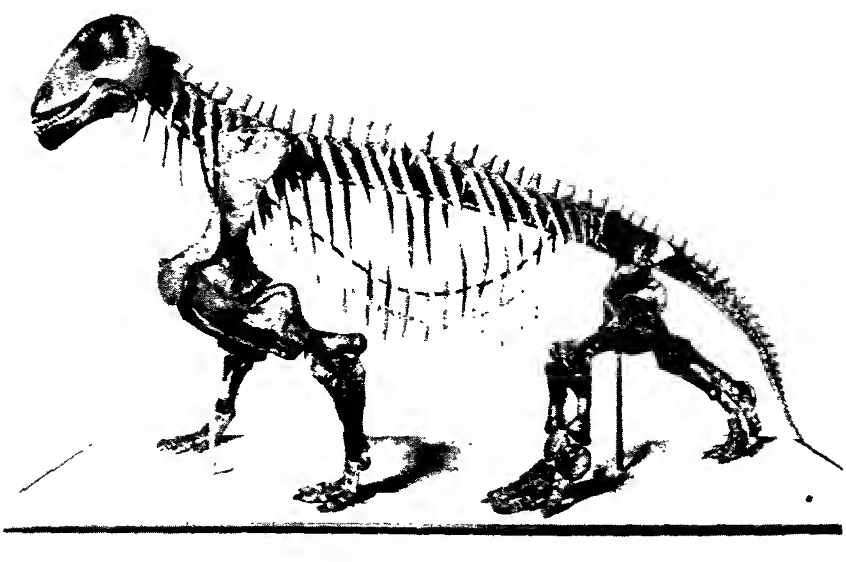


Fig. 4. The complex bridge in the premammalian stage. Skeleton of early mammal-like reptile. *Moschops capensis*. Side view.

At first, progression on the ground was chiefly by wiggling, after the fashion of a swimming fish, but an oblique rocking movement was imparted by the thrusts of the short sprawling limbs. But even at this early stage we have the elements of

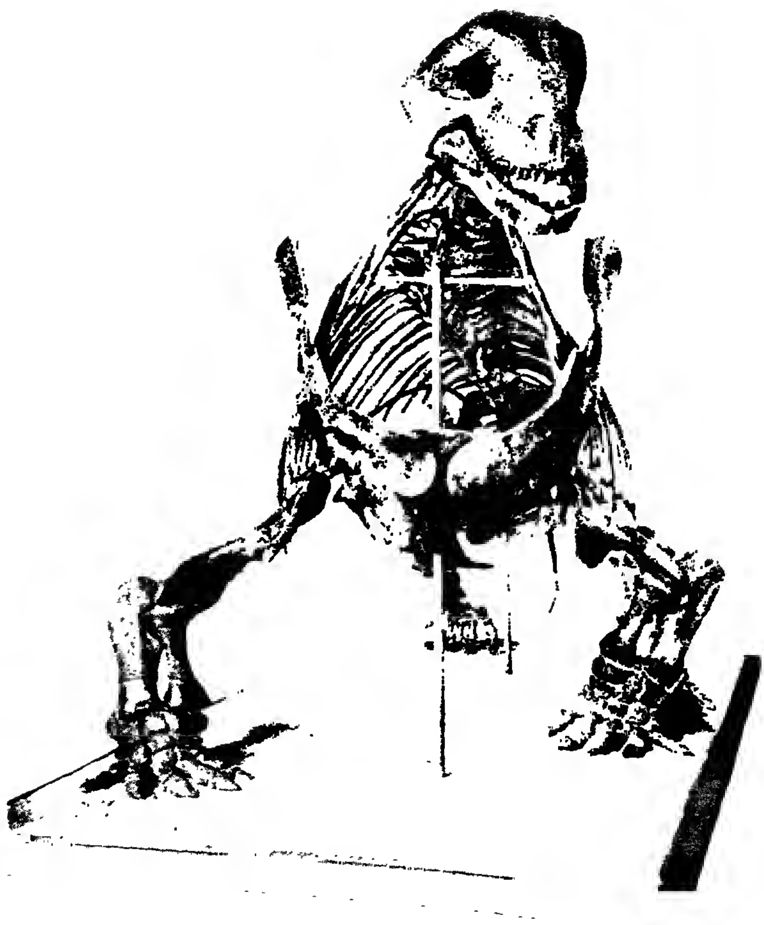


Fig. 5. [illegible] The [illegible] diverge too much in the [illegible]

the jointed movable combined suspension and cantilever bridge, the pectoral and pelvic girdles forming the two piers of the bridge, between which the skull and backbone were suspended. This combination of suspension, cantilever and drawbridge was transmitted to the mammals but in a greatly

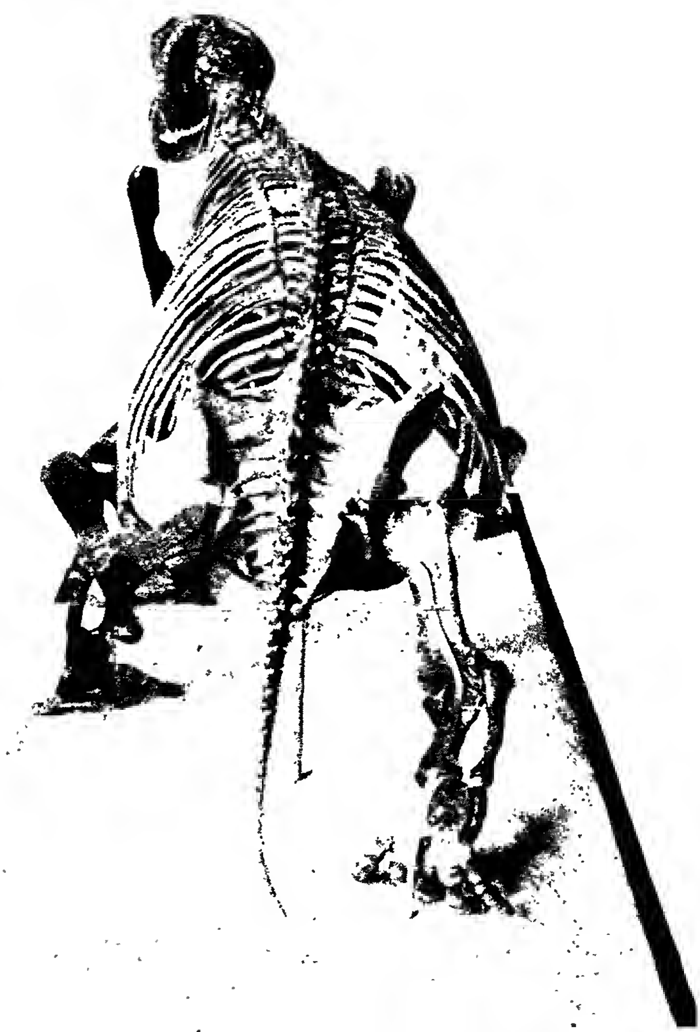


FIG. 6. Contact of pelvis with backbone. Rear view of mounted skeleton of *M*[illegible]

FIG. 7. Di[illegible]-like reptile (M[illegible]). F[illegible] G[illegible] C[illegible]

improved form. When the animal was on land the weight of the skull was compensated by the backward thrust of the occipital condyle on the column and by the pull of the spinal muscles and ligaments along the back. Here again we have the basis of a characteristic mammalian condition.

As soon as vertebrates began to run rather than crawl, the backbone had to meet new stresses. Running necessitates lifting up the head and forequarters, advancing the forelimbs, falling forward and pushing with the hind feet (Fig. 4). By this time the pectoral girdle was free from the skull, a neck had been developed and the skull, neck and thorax were slung between a U-shaped cradle (Fig. 5) formed by the opposite scapulo-coracoid and clavicular arches.

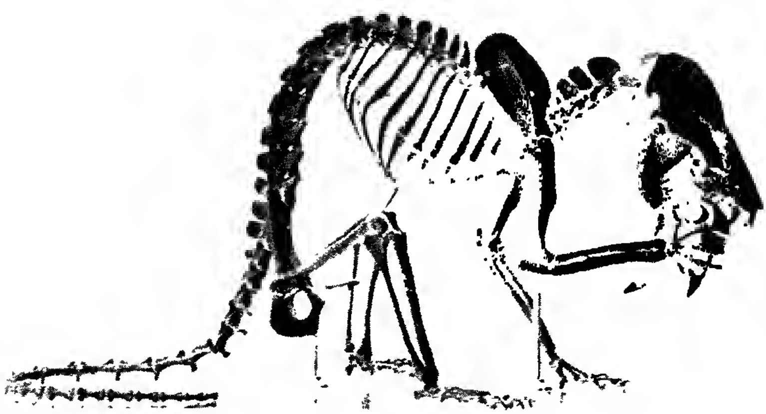


FIG. 8. Skeleton of an opossum. Mounted by S. H. Chubb.

The pelvic girdle (Fig. 6) very early extended dorsad and formed effective connections with the sacral ribs, which transmit thrusts from the limbs to the column.

Each half of the pelvis also serves as the base for a great pyramid of muscles (Fig. 7), which pull the leg forward or

backward, outward, inward, upward or downward. Here again these habitus features of the early tetrapods became part of the heritage of the mammals and by the time of the higher mammal-like reptiles or cynodonts the mammalian grade of organization was being closely approached. For here we find, in addition to the features already noted, a differentiation of the column into atlas and axis, true cervicals, thoracic, lumbar, sacral, coccygeal and caudal vertebræ. The stresses from the skull are transmitted in part to the atlas and axis, but largely to the deep and superficial long muscles of the neck, back and loins.

The same thing is true but in even greater degree in the primitive mammals, as represented by the opossum (Fig. 8).

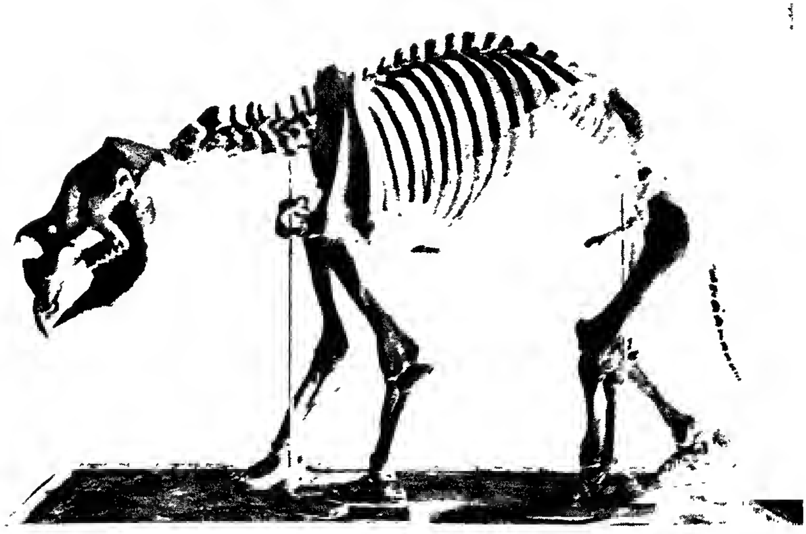


Fig. 9. Cast of skeleton of *Dinoceras*.

Here the highly differentiated column is capable of meeting the diversified stresses of arboreal life, including those transmitted from the relatively large skull.

When the skull becomes very large, heavy or powerful, there are several pathways for distributing stresses to other

parts of the body. In the perissodactyls and artiodactyls, for example, part of the weight of the skull and neck is transmitted to the high spines of the anterior dorsal vertebræ by the powerful ligamentum nuchæ with its many strands, capable of resisting high tensile stresses.

A rather different arrangement is shown in the skeleton of the giant marsupial *Diprotodon*, a cast of which I had mounted in the position shown in figure 9. Here we see that the spines of the anterior dorsal vertebræ are low and it is very probable that part of the weight of the skull was transmitted by the longissimus spinalis muscles to the arch formed by the

FIG. 10 Muscles supporting the head in the elephant. From Cuvier and Laurillard.

posterior dorsals, lumbar and sacral vertebræ. Another part of the weight of the skull was borne by the pectoral cradle, which terminates above on each side in a sort of pointed cap on top of the scapula; this cap must have served for the in-

sertion of the cervical and thoracic slips of the serratus, while the trapezius and the rhomboid muscles above it ran forward to the skull. In the Eocene *Coryphodon* a somewhat similar pointed scapula is seen, probably also for the purpose of contributing to the support of the heavy head. Very probably there was a dorso-scapular ligament which spread from the top of the scapula to the spines of the anterior dorsals.

In the elephant (Fig. 10) the great weight of the head is distributed partly to the neck vertebræ through the deep occipital and spinal muscles, partly to the dorsal vertebræ through the superficial occipital muscles and the longissimus

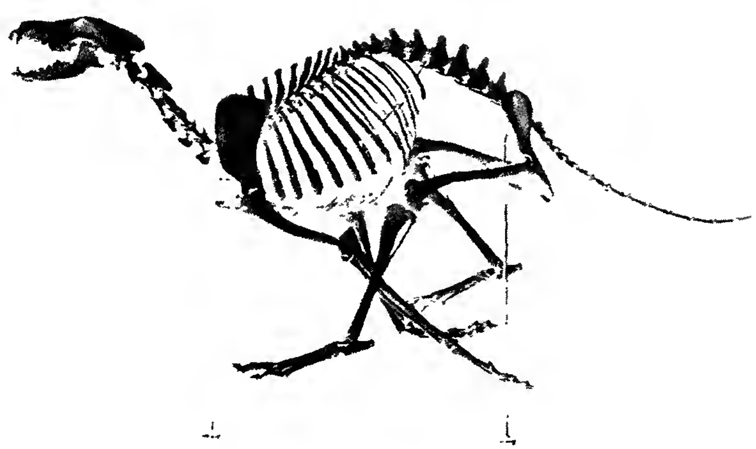


FIG. 11. Spring-like action of the backbone in fast-running animal. Skeleton of Russian wolfhound. Mounted by S. H. Chubb.

dorsi, partly to the top of the scapula through the rhomboideus, splenius and serratus cervicis. From the scapula it is distributed downward and backward through the thoracic part of the serratus to the ribs, and downward through the triceps to the lower arm. In the horse the powerful dorso-scapular ligament plays a part in distributing the stresses from the head and neck to the dorsal vertebræ.

In slow-moving animals, such as the elephant, with massive bodies, long proximal and short distal limb segments, the spines and transverse processes of the lumbar vertebræ are often short.

In animals that leap or run, on the contrary, the muscles of the loins are powerfully developed and with them the lumbar vertebræ and their spines and transverse processes (Fig. 11). In such cases the backbone evidently acts as a

FIG. 12 Bobbing action of the head and neck in running horse. Skeleton of race-horse, Sysonby. Mounted by S. H. Chubb.

spring, working in a vertical plane, and there is an anticlinal vertebra at the top of the arch, where the axial muscles of the loins meet those of the thorax.

In some leaping and running animals, such as the horse (Fig. 12), the bob-like movements of the heavy head and neck play an important part in bouncing the forepart of the body upward so that the forelimbs can be thrown far forward. The sudden retraction of the head and neck are effected chiefly by some of the deep spinal muscles which are inserted into

the dorsal surfaces of the cervical vertebræ. In the horse the concavity of the dorsal borders of the ilia (Fig. 13) permits the forward prolongation of the deep gluteals and their attachment to the longissimus spinalis muscles. When

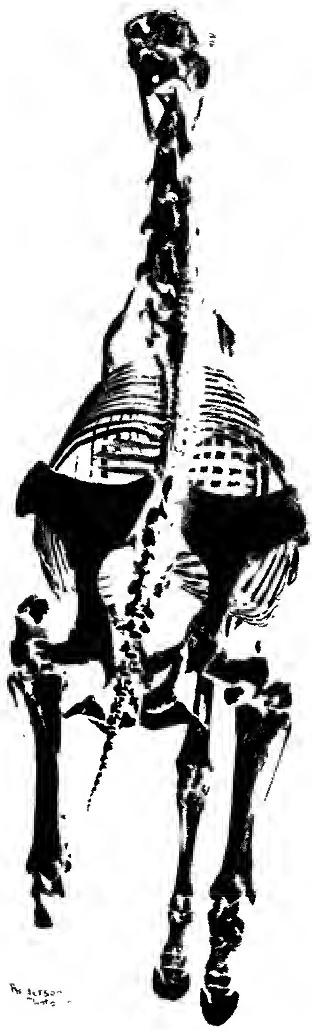


Fig. 13. Rear view of the [illegible]. Skeleton of race horse. Mounted by S. H. Chubb.

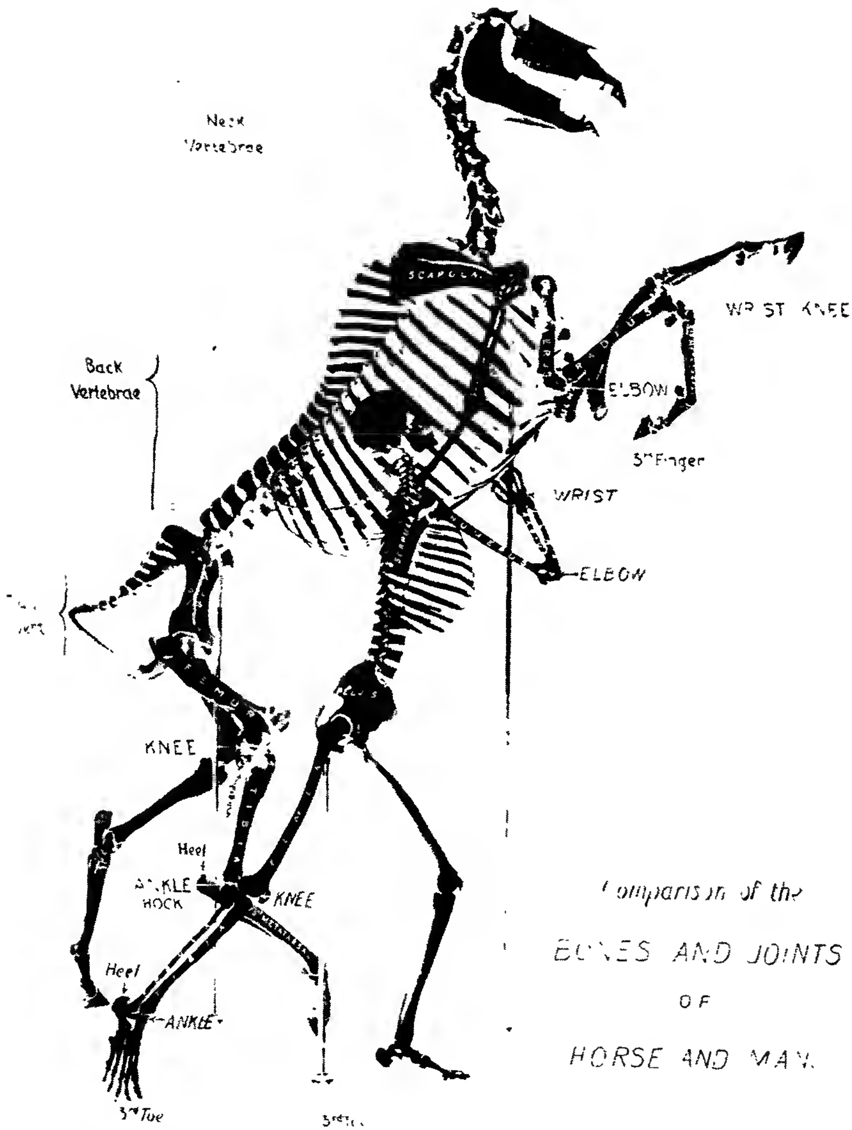


FIG. 14 Comparison of skeletons of rearing horse and man. Mounted by S. H. Chubb

the leg is momentarily fixed, contraction of the deep gluteals and longissimus in tandem tends to raise the forepart of the body on the hip joint.

Thus the drawbridge-like action of the entire spinal column, when it rears up upon the hip joint, is an important part of the locomotor methods of many mammals, such as horse and man (Fig. 14). We have seen that the foundations for this arrangement were laid among the earliest mammal-like reptiles and the case is a good example of the principle that part of the heritage of the remote ancestor contributes to the habitus of its diversified descendants.

In conclusion, the vertebral column of the earlier aquatic vertebrates was adapted chiefly for lateral undulations in a horizontal plane, that of mammals for spring-like movements in the vertical plane. This advance became possible only through the fixation of the sacrum upon the pelvis, so that the vertebral column could rear up in front using the hip-joints as paired pivots. In man, walking erect and transferring all the work to the hind limbs, the bipedal habitus conceals but does not obliterate the remote quadrupedal heritage.

THE SPEARTHROWER IN AUSTRALIA *

D. S. DAVIDSON

(*Read by title April 25, 1936*)

Abstract

The spearthrower was used by Upper Palæolithic hunters in Europe 20.000 years ago but in more recent times it has been employed only in the New World and in the Pacific (principally Australia, but also in a few localities in New Guinea, Yap and the Pelew Islands). It now has disappeared in North and South America except among the Eskimo and in Amazonia, so that its greatest present use is among the Australian aborigines.

This weapon appears not to have a *great* antiquity in Australia for the available evidence indicates that it was not a possession of the earliest Australians. It seems to have spread to the continent from New Guinea not earlier than a few thousand years ago. Even at the present time there are a few Australian tribes who have not yet acquired it and many others in peripheral areas among whom its use is not typical.

The spearthrower is most efficient with light-weight spears and is not practical with extremely heavy spears. Since most Australian hand spears are of considerable weight the adoption of the spearthrower has required many adjustments in these old traditional spear types. Technical considerations thus indicate a chronological relationship between certain specific early types of Australian spear and the spearthrower and substantiate other evidence which suggests that the spearthrower did not arrive in Australia until after several prominent types of spear had been well established. Modern Australian spearthrowers vary considerably in size. Some are broad and leaf-like, others narrow and lath-like in shape, whereas stick-like forms are used in some localities. Thus although the Australians borrowed the concept of this weapon from New Guinea they have altered it in many ways to suit their own ideas.

I

One of the most important inventions in human history is the spearthrower. This device offers a double advantage to those who use spears for it not only increases the leverage of the arm, thereby permitting the attainment of a more distant range, but it also concentrates the entire force of delivery behind the butt of the spear to allow greater accuracy. Equipped with the spearthrower man thus is able to strike from a greater distance and to hurl his spear with more force

* This article is one of the results of a study conducted in Australian Museums during 1930–1931 under a fellowship grant by the Social Science Research Council of New York. Australian Museum, Sydney (AM), Queensland Museum, Brisbane (QM), South Australian Museum, Adelaide (SAM), National Museum of Victoria, Melbourne (NMV); University Museum, Philadelphia (UP).

and increased affectiveness at near range, thereby avoiding some of the hazards previously faced with weapons thrown by hand.

The place of origin of the spearthrower cannot be indicated at present but it seems not unlikely that it was in Asia. These weapons make their earliest known appearance in the Upper Palæolithic Age in Europe but since Europe at that time seems to have received its major cultural stimuli from the east or southeast, the spearthrower may have come from Asia. How long it may have been in use before migrating Asiatics or diffusion introduced it into other areas cannot be intimated.

The relatively great antiquity in Europe and by inference in Asia is not manifest for other parts of the world. In recent times spearthrowers seem to have been confined to two main areas, Oceania and the New World (including adjacent northeastern Asia). In North and South America these secondary weapons still are employed by the Eskimo (and neighboring Siberians) and apparently by a few tribes of Amazonia, respectively, but previously their distribution apparently covered the greater part of the two continents. We know from historical accounts and from archæological investigation that spearthrowers were employed in many regions in the Americas at the time of discovery and that in certain localities they had become extinct only in rather late pre-Columbian times. Such a sporadic distribution, with appearances scattered from the Arctic down the west coast to Peru and with occurrences to the east as far as Florida and Brazil, indicates the prominence which this device at one time or another enjoyed in a large part of the New World. The cause of its extinction in some areas can be attributed to the coming of the Europeans and the subsequent annihilation of native cultures, but long before Columbus set sail the spearthrower had become extinct or obsolete in various other localities, apparently in many instances as the result of the arrival of the bow and arrow. Although the bow and the spearthrower are not incompatible per se, the Eskimo for

example still employ both albeit for different purposes, it seems to be true that the introduction of the former tends sooner or later to relegate the spearthrower to obsolescence and finally to oblivion. At least we know that spearthrowers for the most part are limited to areas where the bow is unknown or of recent introduction, and to times, varying in different parts of the world, which antedate the introduction of the bow and arrow.

In the Pacific the spearthrower in historic times seems to have been confined to Australia, a few localities in New Guinea, and to Yap and Palau.[1] It is only in Australia, however, that it can be said to be typical, for to the north it has all but disappeared apparently as the result of the inroads of the bow, a weapon still unknown in Australia except at the very tip of the Cape York Peninsula. Australia thus is the only continent where the spearthrower continues to be used as a major weapon and the only great land mass which never has been conquered by the bow and arrow.

That all the spearthrowers of the world are historically related seems a plausible hypothesis but one for which there is insufficient evidence at the present time to permit a satisfactory discussion. The antiquity manifest in palæolithic Europe and the greater antiquity inferred for Asia, seemingly antedate the movements of many, indeed if not all, extant peoples from Asia to the Americas, and to New Guinea and Australia. The suggestion that the various historical appearances of spearthrowers are derived ultimately from an Asiatic origin therefore is not inconsistent with current theories of human migrations, in spite of the fact that for Asia actual evidence of great age is lacking at the moment.

The maximum antiquity of the spearthrower in the New World is most uncertain. As the result of the accurate dating by dendrochronology of various pre-Columbian deposits in the American Southwest we know that spearthrowers were used during the second century A.D. (Basket Maker II Times). Presumably here or elsewhere in North America,

[1] Luschan, p. 133.

they antedate this period by millenia but this is conjecture unsupported at present by datable evidence.

The maximum antiquity of the spearthrower in Australia similarly cannot be indicated at the moment but there can be no doubt but that here, too, many hundreds if not thousands of years are involved. The greatest possible antiquity, however, although it cannot be mentioned in terms of years, apparently can be equated relatively in terms of various cultural manifestations.

1. Spearthrowers were lacking in Tasmania where the Tasmanians had been isolated culturally possibly for many thousands of years. It seems permissible therefore to regard the ancient time when the Tasmanians of Tasmania became separated from the Tasmanians of Australia as indicative of the greatest possible antiquity that spearthrowers could have on the continent.[1]

2. A much lesser antiquity, however, seems indicated. That the spearthrower was not brought in by the earliest Australians appears to be demonstrated by its lack of appearance on Melville and Bathurst Islands and in certain areas in eastern Australia, as well as by considerations to be discussed below which seem to show that it has diffused but recently into various other parts of the continent.

3. Lastly, there seems to be a chronological relationship between the spearthrower and various types of Australian spears, a relationship which suggests that a considerable period of time may have elapsed between the initial appearance of Australians and the introduction of the spearthrower.

II

Before we consider the question of the relative antiquity of the spearthrower let us discuss the practical problems of diffusion. At first glance it would appear that the acceptance of this weapon would be a simple matter entailing no great

[1] There is an abundance of cultural evidence to show that the Tasmanians preceded the Australians in Australia. Only two recent writers, Pulleine and Wood Jones, still support the old contention that the Tasmanians reached their islands by sea from some distant locality rather than from Australia.

difficulty in adjustment. However, a moment's reflection is sufficient to indicate that its adoption involves not only changes in motor habits of throwing spears and the acquiring of the ability to fit quickly the spear to the spearthrower, but also the adjustment of spear weights and lengths to suit them for use with the spearthrower.

As is well known there are two classes of spearthrowers which have been termed "female" and "male." The former is characterized by a cup-like depression or concavity near one end into which the butt of the spear is placed for throwing. The ordinary spear thus requires no alteration for use with this class. In the "male" class a projection peg either is carved into or is secured to the shaft of the spearthrower and can be used only with a spear which has had a concavity carved in its butt. Since "male" spearthrowers appear to be the only class employed in Australia, with possibly a few unimportant exceptions,[1] all spears intended for use with spearthrowers consequently must be equipped with a slight concavity in the butt. Presumably, the distribution of the spearthrower can be determined by the appearances of spears with this feature.

It is important to note, however, that the spearthrower cannot be adopted readily by a tribe merely by following the simple process of carving a depression in the butt of each hand spear. Many hand spears can be so transformed and thereafter can be hurled effectively either by hand or with the spearthrower, nevertheless there are many spears which cannot be thrown satisfactorily with the spearthrower. The deciding factor is weight.

Since spears thrown by hand (javelins) quite naturally tend to be held at the balance their maximum possible weight is greater than that of thrusting spears (lances) held near the

[1] They have been reported at Two Fold Bay, New South Wales, at an undesignated locality near the southwestern boundary between Victoria and New South Wales, and at Cooktown, Queensland (Luschan, p. 133). It appears, however, that such spearthrowers could not have been in prominent use in these districts for all the specimens from them known to the writer are of the male class as are the many hundreds from other parts of the continent which he has examined or which are described in the literature. Klaatsch secured a toy of this class on Melville Is. Graebner, 1909, p. 736.

butt end of the weapon. The maximum weight of spears used with a spearthrower is even more limited than that of the latter, for since they must be grasped only at the point determined by the length of the spearthrower, relatively heavy spears cannot be conveniently balanced (Fig. 1). It is

FIG. 1. A Wardaman native (North Australia) using the spearthrower with a light-weight wooden spear fitted with a head of fence wire. Note the sag and the difficulty of balancing even this relatively light-weight spear.

true that a long or heavy spear can be supported partially by the hand of the non-throwing arm until the moment the throwing arm is brought back and the spear, supported by the peg of the spearthrower, becomes poised in the air just as the throw is commenced, but such a procedure, although not unknown in Australia, is awkward and interferes with and restricts the freedom of action so necessary for accurate and forceful throws. However, as a rule only one arm seems to be employed, hence if the most efficient action is to be attained, the weight or length of a spear must be such that not too much tension is placed upon the throwing-arm. Since this stress also depends in part upon the length of the spear-

thrower it follows that extremely heavy spears cannot be thrown with spearthrowers, that relatively heavy spears can be thrown better with short spearthrowers than with long ones and that medium or light weight spears can be hurled with either short or long spearthrowers.

As might be expected for practical reasons spear weights fall well within the theoretical maximum limits, hence there is some overlapping in specimens intended for throwing by hand, for thrusting, or for use with spearthrowers. Nevertheless there is a marked tendency for hand spears as a class to be relatively heavy and for spears thrown with a spearthrower to be relatively light in weight. However, it is important to note that certain types of hand spears on the average are lighter in weight than others and we also find that the specimens on the average in each of the various types of hand spears differ considerably in weight or length from region to region. Since it appears likely that there have been such variations within each type and between types since before the time the spearthrower was introduced into Australia, it follows that spearthrowers could have been accepted quite readily by those tribes which possessed relatively light or medium weight spears, but that other tribes characterized by relatively heavy spears might have found the adoption of the spearthrower difficult. In the latter instance a tribe apparently would have been faced with the problem of manufacturing lighter weight spears of the traditional type, of acquiring a new type of lighter weight spear along with the spearthrower, or of rejecting the spearthrower for the time being, depending on the values they associated with their traditional equipment and with the new device for spear propulsion.

Although it is purely inferential that the diffusion of the spearthrower was either aided or hindered by the prevailing type of hand spear in those parts of the continent where the spearthrower is now well integrated the question is not merely a theoretical one for at the present time we find that the adoption of the spearthrower is being retarded in several

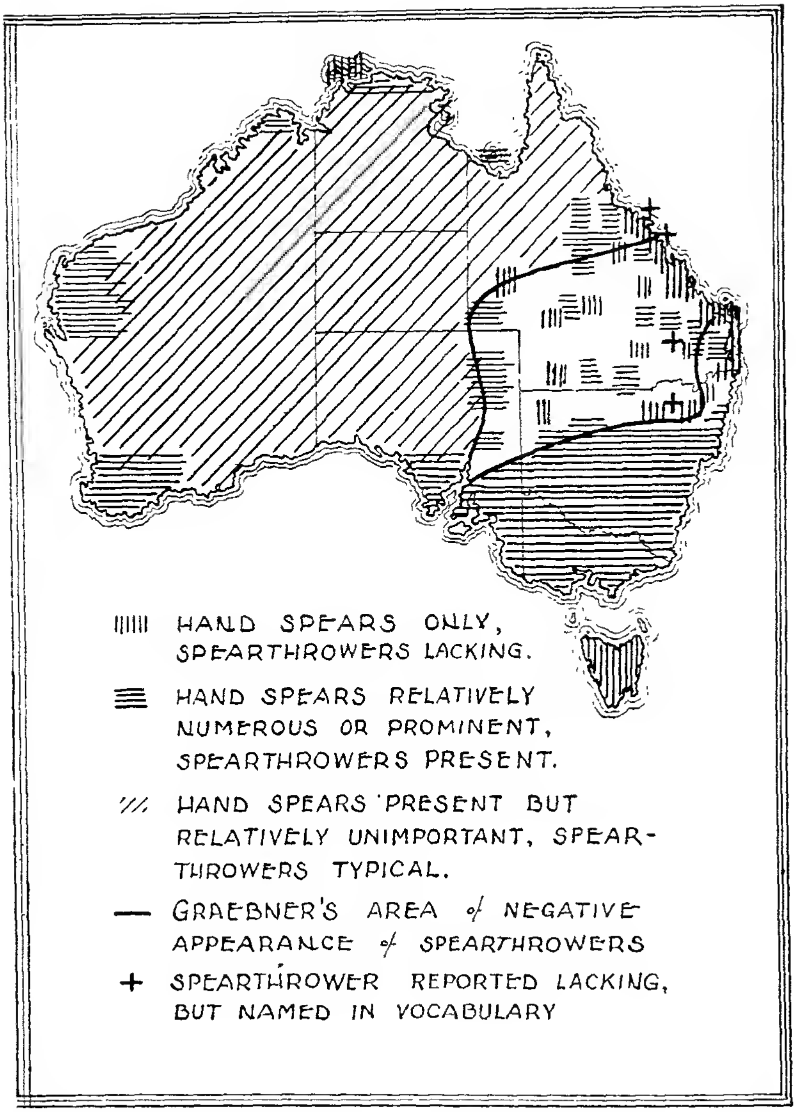


Fig. 2. Distribution of typical appearances of hand spears and of spearthrowers.

Localities in Which a Name for Spearthrower Appears in the Vocabularies but Spearthrower Reported Lacking

Cape Gloucester, Curr., III, p. 4; Namoi and Barwon Rs., p. 311; Port Mackey, p. 51; Dawson R., p. 107; Mary R., p. 197.

regions by the types of spear in use. This question will be discussed in connection with spear types.

III

As is well known the distribution of the spearthrower in Australia in historic times includes practically the entire continent, the only negative areas, aside from Tasmania, being Melville and Bathurst Islands, part of the Queensland coast around Broad Sound, and some interior localities of southern Queensland and northern New South Wales, in all of which spears are thrown only by hand.[1] Thus the spearthrower has all but conquered the continent spacially. However, the intensity of its conquest varies considerably for, whereas in most areas it has relegated hand spears to insignifi-

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LOCALITIES IN SOUTHERN QUEENSLAND AND NORTHERN NEW SOUTH WALES WHERE SPEARTHROWERS ARE REPORTED LACKING

Queensland Coastal Area.—Townsville to Rockhampton, Brisbane, Roth, Bull. 13, p. 197; L. Brisbane R., Curr, II, p. 215; Nogoa and Dawson Rs., p. 473, III, pp. 90, 105; Port Denison and Cape Gloucester, p. 4; Belyando and Cape Rs., pp. 19–20; Port Mackay, pp. 45, 51; Burnett R., p. 109; Port Curtis, Calliope R., Keppel Bay, p. 115; Boyne R., p. 123; Maryborough, p. 135; Great Sandy Is., p. 149; Mary R., p. 158; Stradbroke and Moreton Is., pp. 223, 227, 229.

Interior Queensland.—Thargominda, Curr, II, p. 37; Between Lower Paroo and Warrego Rs., p. 182, III, p. 271; Hamilton R., II, p. 351 (but present among neighbors); Between Thompson and Barcoo Rs., p 378. King's Cr. and Georgina R., p. 366; Blackall, III, p. 77; Roma, p. 253.

Northern New South Wales.—Northwest, Curr, II, pp. 159, 178; Bourke, p. 192; Head of Macintyre R., III, p. 269; Tenterfield, p. 295; Namoi and Barwon Rs., p. 309.

AREAS WITHIN THE ABOVE DISTRIBUTION WHERE SPEARTHROWERS ARE REPORTED PRESENT

Curr, II, p. 373, L. Diamantina R.; pp. 436, 467, 481, Clark and Cape Rs.; p. 447, Cleveland Bay; p. 463, U. Flinders R., Hughenden; p. 467. U. Cape R.; p. 481, Natal Downs; p. 487, Mt. Black; pp. 435, 455, 489, U. and L. Burdekin R.; III, p. 9. Tower Hill and Cornish Crs.; p. 11, U. Thompson R.; pp. 25, 33, Belyando and Cape Rs.; p. 41, Fort Cooper; pp. 75, 81, Barcoo R., W. of Blackall; p. 81, Mt. Enniskillen; p. 89. Ravensbourne Cr.; p. 99, Head of Comet R.; p. 101, Brown R.; p. 107, Dawson R.; p. 133, N. Side Moreton Bay; p. 141, Brisbane-Gympie; p. 151, U. Burnett R.; p. 147; Mary R.; p. 211, U. Brisbane R.; p. 261, Balonne, Narran, Baleandoon, Nogara Rs., p. 267, U. Macintyre R.; pp. 279, 281, 283, U. Warrego and U. Paroo Rs. Roth, Bull. 13, p. 197, Charters Towers.

[1] There may be a few small areas elsewhere. For instance Curr, II, p. 144, reports spearthrowers lacking in the Yorke Peninsula, South Australia. However, spears with a concavity in their butts labeled from this area are found in SAM. Flinders, II, p. 66 (1814), reported the spearthrower lacking at King George Sound. He may have been in error but his statement is of interest since it indicates that this weapon may not have been in prominent use if it were present.

cance, there are still many regions within its distribution in which hand spears are numerous, or even prominent. These regions include northern North Australia, the northern Kimberley district, the Northwest (Ashburton-Gascoyne), the Southwest, southern South Australia, the Southeast and the Wellesley Islands, all located in peripheral or isolated areas, many of which would be among the last to receive the spearthrower entering the continent at Torres Strait (Fig. 2). It is quite possible that the spearthrower arrived in some of the districts in these regions within the memory of living natives. On the other hand, the process by which spearthrowers become thoroughly integrated in native culture may be a slow one, depending in part upon the types of spears present and the difficulties in adjustment, so that the conditions now found in some peripheral areas may not reflect necessarily an introduction of only a few years, but in part the slow process of integration of a trait superficially used possibly for a few generations. Inquiry in those areas where aboriginal culture still flourishes might solicit important information in this respect.

In all other parts of the continent hand spears seem to be decidedly rare or of little practical significance.[1] Available information indicates that they generally are non-typical or relatively scarce throughout most of northern Queensland, northern South Australia, Central Australia, most of North Australia and eastern and central Western Australia in all of which regions spearthrowers are typical. Since it is principally in peripheral regions, inland as well as coastal, where the spearthrower is not thoroughly integrated it would seem that this weapon has reached many of them in relatively recent times, and that a slow process of integration still

[1] For many districts the museum collections contain no hand spears, although spears for use with spearthrowers may be well represented. It seems likely that the former are used at least occasionally in all these localities, but the evidence suggests that they are not prominent. Occasionally we find them used in ceremonies but otherwise having little if any utilitarian value, for example, the heavy, plain "King" spears of Central Australia. Such an employment possibly indicates a local traditional association, retained from times which antedate the introduction of the spearthrower, between an early type of spear and certain types of ceremonies.

continues. Possibly only a few centuries ago, therefore, the spearthrower may have been unknown in many, indeed if not in all of these peripheral areas.

The evidence which indicates a chronological relation between various types of Australian spears and the spear-thrower has been presented elsewhere.[1] On the basis of geographical distribution, technical considerations and the known directions of diffusion of certain types of spears in local areas the order of appearance has been inferred as follows:

FROM NEW GUINEA

Relatively heavy one piece hardwood hand spears	1. Plain spears (Brought in by Tasmanians and possibly by Australians) 2. "Death spears"[2] (Possibly brought in by Australians, received by diffusion or developed in Australia) 3. Spears with barbs cut in the solid (Diffused)
	4. The spearthrower (Diffused)
Composite spears thrown only with spearthrowers	5. Reed spears (Reed shafts and plain hardwood heads) (Diffused)
	6. Detachable barbs (Diffused)

MAIN SUBSEQUENT DEVELOPMENTS IN AUSTRALIA

Composite spears used almost exclusively with spearthrowers	The change from the relatively heavy one-piece spears to composite spears by combining heads of Types 1, 2, and 3 with reed, bamboo or light-weight wooden shafts; the substitution of light-weight detachable barbs[1] for the heavier barbs cut in the solid; the application of stone heads to light-weight wooden shafts or to reed type spears (local to western North Australia and northeastern Western Australia).

That the spearthrower diffused to Australia prior to the reed spear seems indicated by both distributional and technical considerations. Reed spears are found only in part of the distribution of the spearthrower, principally in northern, northeastern and southeastern Australia, and appear to be lacking in areas where the spearthrower is unknown. Since they are too light in weight to be thrown satisfactorily by hand, and in so far as is known are always thrown with a spearthrower, although occasionally used in the hand for

[1] Davidson, 1934.

[2] The term "Death spear" has been applied to plain acicular spears with heads equipped with a series of spicules of stone set into gum along the shaft.

jabbing fish, it may be that their development in New Guinea (or elsewhere) was in direct response to the recognition that spearthrower efficiency is greatly increased with light-weight spears. They are easily made, possess a natural concavity in the butt, and a native can carry great numbers of them. It also is possible that these spears developed from arrows.

That the spearthrower arrived in Australia subsequent to spears with barbs cut in the solid seems demonstrated by a number of facts. These spears are typical in areas where the spearthrower is lacking, Melville and Bathurst Islands,[1] the Broad Sound region of Queensland, and in the Bourke district of New South Wales. They seem to be the main type of one-piece spear which has been difficult to adapt to use with the spearthrower, probably as a result of their relatively heavy

[1] On these islands off the coast of North Australia the spearthrower is lacking, except for the toy found by Klaatsch, but the natives are acquainted with its use on the mainland. It seems facetious to say that they have not accepted it merely because they do not desire it for there should be some better reason, whether the local blackfellows are aware of it or not, why they reject a device which has so impressed most other Australians that it has been accepted throughout almost the entire continent.

Although the islanders may be conservative to the point that they resist the rapid spread from the mainland of new principles, the latter cease to be strange or radical in the course of time. It would seem, therefore, that since the spearthrower has been used on the adjacent coast of the mainland for more than a century that any resentment towards it by the islanders would have tended to disappear. Hence when we find that even today the spearthrower is making no inroads on the islands we should seek other explanations.

One factor which certainly has not encouraged the introduction is the weight of the local spears. These weapons as a class are the heaviest made by Australians and are wholely unsuited to spearthrower use, although a few of the lighter specimens may overlap with some of the heavier spears thrown with the spearthrower in various parts of the continent. Perhaps the islanders associate spear efficacy with relatively great weight and regard light weight spears as unsatisfactory weapons.

Other factors which may have influenced the situation are the prevailing type of spear in use on the islands and the apparent pride in workmanship associated with its manufacture. The typical spears are equipped with barbs cut in the solid and are without equal in respect to the skillfully cut, numerous, closely spaced, long, flaring barbs and in the ornate painted decoration subsequently applied. This elaborate arrangement which often extends more than three feet along the shaft gives the forepart of the weapon such great weight as to make these weapons ill-suited for use other than by hand. It is important to note that the similarly made but lighter weight one-piece spears of the adjacent mainland also tend to be thrown only by hand. Possibly the pride in the ability to produce such remarkable specimens may have contributed in part to the decision by the islanders to retain these forms and reject the spearthrower rather than to possess the latter and sacrifice the opportunity to continue their tradition skill in spear manufacture.

weight, for they now are prominent only in certain peripheral areas which would be among the last to be invaded by the spearthrower, the northern coast of North Australia,[1] the Southeast,[2] the Northwest,[3] and the isolated Wellesley Islands,[4] in all of which they are the principal hand spears, although some are thrown with the spearthrower the proportion varying from area to area. Their greatest and most typical use with the spearthrower is found in areas where heads of this type have been combined with lighter-weight shafts, most of North Australia and central Western Australia,

[1] On the mainland opposite Melville and Bathurst Islands, particularly the Coburg Peninsula and eastwards, the spearthrower seems to be commonly employed with medium or lightweight composite spears, but seldom with the relatively heavy one-piece spears similar in type to those used on the islands. Since the former, which represent various combinations of reed, bamboo or light-weight wooden shafts and plain or barbed hardwood heads or stone heads, seem to have been derived from tribes to the south, it appears that the heavy one-piece spears constitute an earlier type which has not yet been adjusted to use with the spearthrower, nor completely replaced by types suitable to the latter as, for the most part, in the regions immediately to the south. It would seem, therefore, that the conditions on the mainland and on Melville and Bathurst Islands are but different aspects of the same question, that the same type of spear has been resisting the spread of the spearthrower on the mainland as on the islands, and that although on the continent there may have been some reduction in the weight of recently manufactured one-piece spears in order to adjust them to the spearthrower, the latter has been successful in invading the coastal country principally because other types of lighter weight spears have diffused along with it or in its wake.

[2] In Victoria, the Lower Murray Valley and probably much of New South Wales, a large proportion of the spears in historic use were thrown by hand, particularly fighting spears. The typical hand spears of this region are of the same type as on Melville Island, but are equipped with fewer barbs and on the average are much lighter in weight. Although some of these spears were thrown with the spearthrower, the latter was employed principally with the light-weight reed spear. It would seem, therefore, that the Southeastern natives were extending the use of the spearthrower to their older type of one-piece spears, but that there was some difficulty in complete adoption as the result of the peculiarities of their older, heavier spear type.

[3] In the Gascoyne-Ashburton area in the extreme northwestern part of the continent, the prevailing type of spear also is relatively heavy and equipped with barbs cut in the solid. It is extensively employed by hand for both throwing and thrusting. Reed spears are still unknown in this region, but an adjustment in weight is found in most of the spears thrown with the spearthrower in the use of composite wooden spears, equipped with the same type of head but with a lighter weight shaft.

[4] This group of islands, only a few miles off the Gulf Coast of northwestern Queensland, seems to have been more or less isolated from influences which passed along the nearby mainland. Perhaps this isolation, as on Melville and Bathurst Islands, has led to a conservatism which hinders rapid cultural change. At any rate we find these islands characterized in general by backward conditions. Although the spearthrower is present it seems to be used with only a small percentage of spears, most specimens being of the same relatively heavy type with barbs cut in the solid as in the other peripheral areas considered.

where hand spears are scarce.[1] In both these regions spearthrowers have a somewhat greater antiquity than in the adjacent peripheral areas, having passed through the former to reach the latter, a plausible explanation why the adjustment of spears to their use is more complete.

The present scattered appearances of spears with barbs carved in the solid indicates that their distribution formerly was contiguous. Since the positive appearances are separated by reed spears, so intimately associated with the spearthrower, and by detachable barbs, so well suited because of their light weight to spears thrown by a spearthrower, it would seem that the acceptance of the spearthrower in much of Australia has been the cause of the decline and disappearance of spears with barbs carved in the solid.

What has been regarded as a perplexing aspect of spearthrower distribution is the area of so-called "negative" appearance centered in southern Queensland as determined by Graebner[2] and accepted by implication by Sollas[3] and Radcliffe-Brown. Suspicion that this extensive region was not as "negative" as claimed first seemed warranted to the writer on theoretical grounds, for the very presence of the spearthrower in the Southeast implies that diffusion passed

[1] The reasons for believing that composite wooden spears as a class represent adjustments resulting from the needs of the spearthrower for spears of medium weight include: (1) Composite wooden spears are rarely manufactured solely for use as hand spears, but almost exclusively for use with the spearthrower. Obviously they can serve as hand spears if necessary. (2) They are not found outside the distribution of the spearthrower. (3) They or reed type spears are used everywhere within the distribution of the spearthrower except along the southern coast west of Spencer Gulf where the one-piece spears thrown by hand are of medium weight and, therefore, require little if any adjustment, aside from the cutting of the concavity in the butt, for use with the spearthrower.

[2] As delimited by Graebner, 1905, p. 30, the northern boundary commences on the Queensland coast near Mackay, extends westward almost to the border of Central Australia, thence southward to the head of Spencer Gulf. From the Gulf of St. Vincent, a few miles to the south, it proceeds northeastwards to near Wilcannia whence it seems to follow the Darling and Barwon River valleys to the neighborhood of Goodiwindi, thence northward to meet the coast near Gladstone, south of Mackay.

[3] Sollas, who based his map on Graebner and Curr, has indicated a somewhat larger area, but since he was interested primarily in plotting the distributions of specific types of spearthrowers his blank region includes not only districts in which spearthrowers were lacking but also localities where they were present but unidentified as to type.

through at least a part of southern Queensland. In addition, the crude stick-like forms and the solid projection peg of some of the spearthrowers in New South Wales and Victoria find their nearest counterparts in northwestern Queensland and the Wellesley Islands.

We might be inclined to assume that spearthrowers spread through the intervening "negative" area so rapidly and affected local culture so superficially that they subsequently fell into disuse and left no traces of their previous existence. Such an explanation might hold for some traits but the very character of the spearthrower indicates that it is not a trait which can be readily acquired and easily forgotten for its use involves an integration affecting spear types, the manufacture of spears and certain acquired habits of employment. For these reasons it seems contrary to reason to believe that the spearthrower could have been passed on from tribe to tribe unless each of them had completely adopted it with all its ramifications.

However, if such had been the case we would hardly expect the spearthrower to become universally obsolete in this region, for once a trait becomes integrated in a culture it tends to remain unless replaced or outmoded, and there are no indications that the spear has lost its significance as the prime weapon in this area or that other methods of spear propulsion have been acquired.[1] Thus the conclusion of Graebner that the spearthrower had passed into disuse because of the arrival of what is called the "Two Class" Kulturkreis,[2] which incidentally did not eliminate this weapon in other parts of the continent, did not seem reasonable to the writer, nor did the suggestion of Radcliffe-Brown [3] that one interested in explaining this peculiar distribution would conclude that the disuse commenced at one point and spread to the entire "negative" region.

[1] Throwing-clubs were present in this area but are not known to have been given more prominence than in other eastern localities where spearthrowers were in use. See Davidson, 1936. Furthermore, the elevation of throwing-clubs to a position of first rank would not necessarily interfere with a method of propelling spears.

[2] Graebner, 1909, p. 739; 1905, p. 35.

[3] Radcliffe-Brown, p. 369.

There also are reasons which imply a relatively recent use of the spearthrower within parts of this area. The presence in the Southeast and in northern Queensland of reed spears and of bone detachable barbs (which are closely but not exclusively associated with reed spears) suggests that spearthrowers were still in use in southern Queensland when these later traits diffused southwards. Lastly, recently acquired information shows that spearthrowers are still in use although of little importance in much of the "negative" part of South Australia.[1]

In view of these facts and considerations, the writer was prompted to consult the details in Curr, Graebner's main authority, and was astonished to find that although Graebner had accepted the evidence which denied the presence of the spearthrower in certain districts he had missed or dismissed an abundance of data which reported spearthrowers present in many localities, information secured by Curr from various individuals and generally accompanied by the local name for the weapon. Indeed, the number of positive localities reported (over two dozen) is approximately equal to the number of negative districts given in the same source.[2]

These positive localities (Fig. 2) change completely the complexion of the problem, for instead of a large "negative" area we are confronted by one in which spearthrowers are sporadically present and distributed in such a manner that a contiguous historic distribution from New South Wales to northern Queensland is all but demonstrated. Unfortunately we have no information concerning the types of spearthrower

[1] Formerly reported lacking among the Wailpi tribe, Flinders Ra., Hale and Tindale, 1925, p. 47. Mr. Tindale has since informed me that they are known but seldom made, the natives preferring hand spears and throwing-clubs.

[2] See legend, Fig. 2. Curr also informs us of several districts in which a word for spearthrower appears in the local vocabulary in spite of the fact that the weapon was reported to have been lacking. It cannot be argued that the spearthrower necessarily was formerly present in these districts for names can be acquired from neighboring tribes without the accompaniment of the object they represent. Indeed, since Australians often travel far from their tribal habitat to attend great ceremonies, it is possible that a name may have been brought home from some distant area. On the other hand it is conceivable that the spearthrower may have been tried temporarily in some of these regions and subsequently discarded as unsatisfactory because its adoption required changes in the traditional type of spear or for other reasons.

used in these localities, hence it is impossible to determine whether the local weapons in recent use were like those of New South Wales or northern Queensland. It is interesting to note in respect to reed spears that although the spear-thrower occasionally is reported alone, reed spears, with but two exceptions,[1] are found only in districts where the spear-thrower is present, a fact which seems to substantiate the opinion that the former is dependent upon the latter as a vehicle for its diffusion.

The negative districts still remain to be explained. Were spearthrowers formerly present but passed into disuse as others have suggested or had these weapons never been accepted in these localities? There are no facts which support the former possibility but there are strong suggestions that spearthrowers may never have been present in these districts. At Broad Sound, Queensland, and Bourke, New South Wales, spears with barbs cut in the solid were present. For these two specific areas, therefore, the lack of spearthrowers may be attributable to the same cause as in other parts of the continent where this type of spear prevails. Possibly a similar explanation holds for the other negative localities but the "war" spears (hand spears) reported by Curr are not known as a class to be of this type. However, there can be little doubt but that spears with barbs cut in the solid were formerly of common appearance throughout northern New South Wales and southern Queensland if we may judge from their known distribution in the surrounding areas, the South-east, eastern South Australia, Bourke and Broad Sound. Thus this type may have been the main factor which hindered the acceptance of the spearthrower in many districts in this general eastern area.

In terms of spear types, therefore, it would seem that the spearthrower in Australia is of relatively recent introduction. What this may mean in years cannot be intimated at the moment but it is to be hoped that archaeology eventually will

[1] Port Denison-Cape Gloucester, where the spearthrower is denied, although a word for it appears in the vocabulary, and the Nogoa River (which part is not specified). Curr, III, pp. 7, 93.

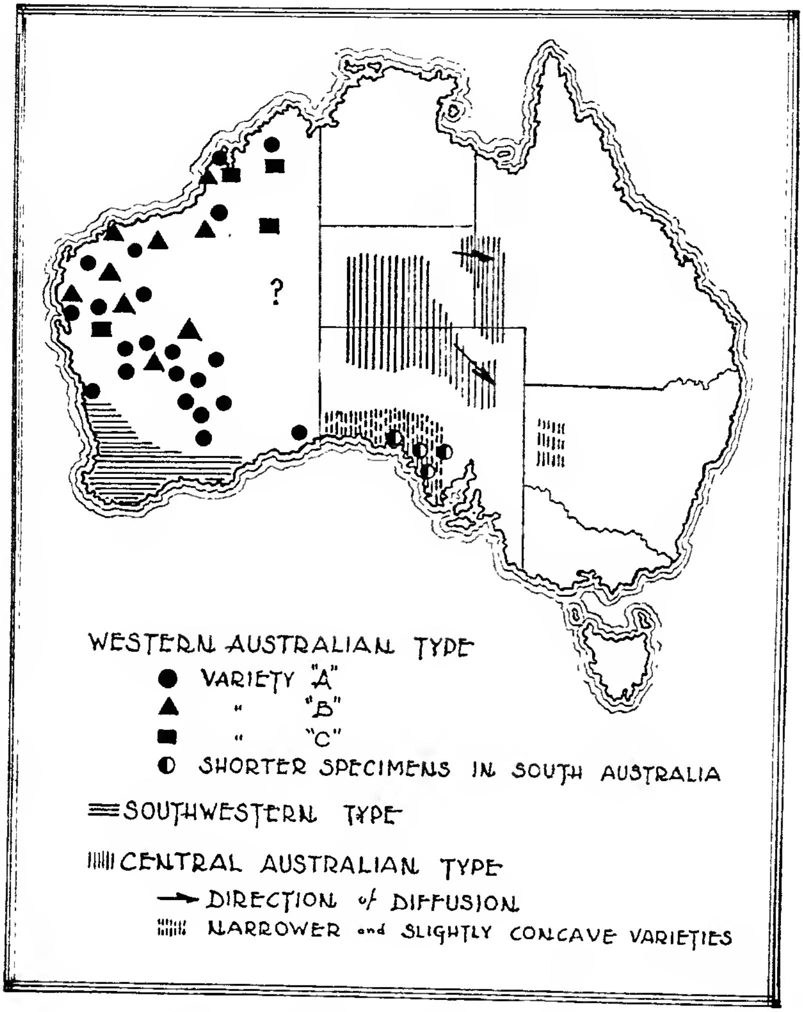

FIG. 3. Distribution of broad spearthrowers.

Variety A (Fig. 4 *a*, *b*).—UP—Kalgoorlie, Albany, Mt. Vernon, Norseman, Peak Hill, Stake Well, Mt. Warren, Mt. Sir Samuel, Menzies, Pingerra. WAM—Kimberley (?), Ashburton R., Wiluna, Murchison, Kookynie. Victoria Desert, Geraldton, Hampton Plains, Eucla. SAM—Carnarvon, Gascoyne, Cygnet Bay. Clement, Pl. 3, Desert south of Broome, Tableland south of Roebourne, Sherlock. Shorter specimens come from South Australia. SAM—Perong, Streaky Bay, Gawler Range, Denial Bay, Fowlers Bay.

Variety B (Fig. 4 *c*).—UP—Warburton Range, Maninga Marley. SAM—Desert 120 miles from Nullagine, Carnarvon, Gascoyne, Lyons River. WAM—Ashburton, Pilbara, Beagle Bay, Beyond Halls Creek. Clement. Pl. 3, Roebourne, Desert South of Broome.

furnish us with some clues, concerning either the antiquity of the spearthrower itself or of the different types of spears, which will permit the inference of maximum or minimum age for the spearthrower.

IV

Spearthrower Types

Modern Australian spearthrowers appear in a great variety of forms, of which some are of widespread distribution whereas others are confined to local areas. To arrange them in a satisfactory classification is difficult for the differences in many instances are less pronounced than the similarities. Furthermore, the extremes in variation of some of the most specialized forms overlap with other types so that there are numerous borderline specimens which could be placed in one group or another.

The most satisfactory basis for classifying spearthrowers is the shaft. Although there is considerable variation in the minor details, it is convenient to arrange all specimens into three classes: (1) broad leaf-like or paddle-like spearthrowers; (2) lath-like spearthrowers with two partially flattened surfaces; or (3) stick-like spearthrowers with shafts round in cross-section.

Variety C (Fig. 4 *d, e*).—WAM—Kimberley, Northwest, Lake Disappointment, Greenough. SAM—Gascoyne. UP—Pender Bay. Carnegie, p. 341, Northern Desert.

Variety D.—Central Australian Spearthrower (Fig. 4 *f*).—SAM—Coopers Creek, Musgrave Ra., Attack Creek, Macdonnell Ra., Tempe Downs, Everard Ra., 200 m. north of Coopers Creek, Barrow Creek. AM—Urandangie, Glenormiston, Linda Creek (all in Western Queensland). Spencer and Gillen, 1904, p. 667, common throughout Central Australia, but not north of Barrow Creek; 1899, p. 582, Urabunna, Ilparra. White, p. 728, and Helms, Pl. XIV, Everard Ra. Roth, 1897, p. 149 and Pl. XXI, Upper Georgina R., Upper Mulligan R., Toko Ranges. Arunta influences among Wonkonguru, Horne and Aiston, p. 80.

Narrow and Slightly Concave Variants.—SAM—Gawler Ra., West coast of South Australia to Eucla, Eurowie, N.S.W. (Fig. 9 *i, j*), Schürmann, p. 214, Port Lincoln.

Southwestern Type (Fig. 4, *g, h*)

WAM-SAM-UP—Very broad in South to narrow at Lake Way in North. Hassell, Esperance District (often with a kangaroo tooth in the handle). Nind, p. 26, reports the use of stone blades.

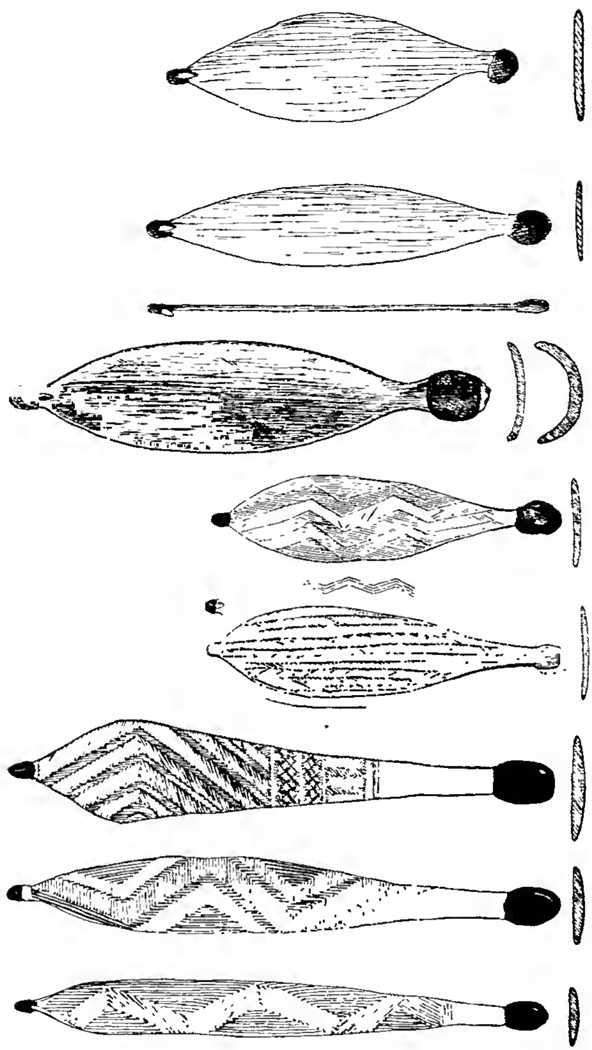

Fig. 4. Leaf-like spearthrowers. *a-c*. Western Australian type (UP). *a, b*. Variety A, Murchison District. *c*. Variety B. Northwest. *d, e*. Variety C. *d*. Pender Bay. *e*. Gascoyne. *f*. Central Australian type (Variety D). *g, h*. Southwestern type (WAM).

1. *Broad Spearthrowers*

Broad spearthrowers are contiguously distributed from western Queensland to the western coast and from northern Western Australia to the southern coast (Fig. 3). Five important forms can be distinguished.

Southwestern.—The Southwestern spearthrower (Fig. 4 *g*, *h*) is limited to the area between the Lower Murchison and the southern coast. Specimens of this type are made of exceedingly thin wood, are relatively short (18 to 30 in.) but exceptionally broad in proportion. Widths of from 4 to 6 or more inches are not uncommon in the Perth-Esperance region, but narrow forms are found to the north. The latter in general outline are not dissimilar from the typical broad type of spearthrower in Western Australia. Indeed the differences seem attributable for the most part to technical factors, for the Southwestern specimens are made from "raspberry jam" wood, which splits easily into thin, flat planks. Their flat character and shape of cross-section, therefore, are fixed and variation is limited to breadth and length.

This type is characterized by a gum knob handle, which generally lacks a stone or tooth blade, and which usually projects to the left on the peg side of the weapon. Incised designs are lacking. With the possible but unascertained exception of the southwestern coastal districts, lath-like spearthrowers also are employed throughout the distribution given.

The Western Australian-Central Australian-South Australian Type

The broad spearthrowers, commonly distributed in most of Western Australia, South Australia and Central Australia are leaf-like or paddle-shape in form and are characterized by a gum knob handle often equipped with a stone adze blade. The Western Australian specimens and most of those from South Australia carry incised designs on the face and may be slightly concave. The Central Australian examples seldom have incised decorations and usually are deeply concavo-convex in cross-section.

For Western Australia and South Australia three varieties can be recognized, each characterized by differences in form and decoration. However, since their distributions overlap considerably, there is not a consistent correlation between shape and style of decoration.

Variety A. The most common form has a maximum length of about three feet and a width of from two to five inches (Fig. 4 *a*, *b*). The narrower examples thus are indistinguishable from the Western-Southern lath-like type (Fig. 6 *f*). In the broader specimens the greatest width tends to be found at about the middle of the weapon, as in the Southwestern type, whence there is a gradual curve towards each extremity. There is some variation in cross-section from concavo-convex to plano-convex, the former tending to be found in the South, the latter in the North.

The characteristic incised design is the longitudinal zigzag motif so extensively employed on bullroarers and churinga in Western Australia. There may be one or more main elements, depending often upon the width of the specimen, each zigzag consisting of a series of short, parallel lines, usually horizontal but occasionally diagonal and about an inch in length (See illustrations). The remaining surface, including the spaces separating the main elements when more than one zigzag is employed, is filled with parallel longitudinal incisions. In Western Australia this type is commonly distributed from the Northwest diagonally across the state to Eucla. It appears to be lacking in the extreme Southwest, in the northern Kimberley and adjacent regions, and possibly in some of the western coastal districts. Somewhat shorter specimens with similar decorations are found in southern South Australia as far east as the Gawler Range. Some examples have a slightly concavo-convex cross-section but others are plano-convex or bi-convex.

Variety B. Spearthrowers of Variety B are fundamentally similar but differ in that the greatest width is located a few inches from the peg end of the weapon, whence the sides taper gradually toward the handle (Fig. 4 *c*). The gum knob

handles, sometimes equipped with a stone adze, are unusually large (3 to 4 × 3 in.). The face may be flat or slightly concave. Along one edge of the back there often is a series of notches across which a stick is rubbed for accompaniment to music.

The incised decoration on the face consists as a rule of a series of parallel zigzags arranged longitudinally as in Variety A, but covering the entire surface. Usually these zigzagging elements alternate regularly in width, the wide ones being filled with incised lines running consistently in one direction, the narrow zigzags with lines running in a different direction, in effect a variant herring-bone pattern. In addition, we generally find the decorated space divided into three horizontal panels of about equal size, each characterized by a different arrangement in the direction of the zigzags, or particularly in the panel nearest the handle, even by unusual or unique decorative patterns. Occasionally a few parallel zigzagging lines are incised on the back.

The distribution appears to be centered in the Northwest. Most specimens come from the area between the Upper Murchison and Kimberley districts.

Variety C. These spearthrowers are concentrated in the Gascoyne-Kimberley region. Like other northern specimens they tend to be plano-convex in cross-section. The main distinguishing features, not invariably present and with many variations, include a relatively short length of about two feet, a medium sized gum handle often equipped with a stone adze blade, a relatively wide body with sides either parallel of curved in arc-like proportions, and a fairly distinct short shaft separating the grip from the flaring portion of the weapon (Fig. 4 *d*, *e*).

The typical incised design on the face consists of a series of parallel longitudinal grooves more or less evenly spaced, with the intervening surface filled with short parallel diagonal lines which alternate in their direction to give a herring-bone effect. In some instances the longitudinal furrows are replaced by zigzagging grooves. A few specimens are decorated

with odd designs. On the obverse the decoration, if present, is similar to that on the backs of Variety B spearthrowers. Along one edge of the back there may be several notches for use as a musical rasp.

The Central Australian Spearthrower. Variety D. The spearthrowers of Central Australia are quite similar to those of the West in their general leaf-like form but differ principally in that (1) the greater percentage are concavo-convex in cross-section, (2) the depth of the concave surface generally is much greater than in other varieties, and (3) incised designs usually are lacking (Fig. 4 *f*).

Variety D spearthrowers in their pronounced form are found from Barrow Creek to northern South Australia and from western Queensland to an undetermined boundary in eastern Western Australia. Shallower, narrower or variant forms also appear throughout this distribution and have been collected further afield; in southern South Australia where Variety A spearthrowers are present, and to the eastward among the Wonkonguru (attributed to Arunta influences) and at Eurowie, New South Wales. An eastward diffusion into western Queensland has been noted by Roth, who found the introduction of these broad spearthrowers to have been so recent in the Boulia area that the local natives, accustomed to the Queensland lath-like form, were unable to throw spears with them. On the northern boundary the Kaitish are said to manufacture relatively crude specimens. The best examples seem to be made by the Loritja of southwestern Central Australia.

Central Australian spearthrowers are used for a number of purposes. The stone blade in the gum handle makes them useful as adzes. The deeper specimens serve as trays. They are commonly employed for fire-making by the sawing of one edge across the face of a softwood shield. The edges of some specimens are crenated for use as a rasp and they also may be tapped with boomerangs or sticks for musical accompaniment. In Western Queensland, if not elsewhere, the sharp edges are employed for striking. Thus in one implement there are

various combinations of spearthrower, adze, tray, fire-saw, musical instrument and striking weapon.

It would thus seem that if we dismiss those differences resulting from technical limitations, presence or lack of incised decoration, variations in degree of concavo-convex cross-section or in the location of the greatest width of the surface, we are dealing with but one fundamental type of broad, leaf-like spearthrower from western Queensland to the far West and from the Kimberley district to the southern coast. Within this area the western and southern tribes have emphasized the application of incised designs; those in the Northwest have placed the greatest width near the peg end of the weapon. The Central Australians have gone to the extreme in producing a deeply concave upper surface, whereas the southwestern aborigines, because of technical factors, have manufactured a thin, flat, broad variety. The contiguous distribution not only suggests historical unity, but also that the broad spearthrowers may not have a great antiquity, relatively speaking, but represent a specialized development indigenous to the area in which they are now found. The little ethnological information we have in respect to diffusion supports such an inference.

2. *Lath-like Spearthrowers*

Spearthrowers with lath-like forms can be classified into four types, of which three are important and of widespread use (Fig. 5). These can be termed: (1) the Queensland, (2) the North Australian, and (3) the Western-Southern types. The fourth, found in a small area in northwestern North Australia can be designated, for convenience, the Daly River type.

Queensland Type

The characteristic spearthrower of northern Queensland and the Cape York Peninsula, including some of the islands in Torres Strait, is thin, straight and lath-like in shape (about $30 \times \frac{3}{8} \times 1\frac{1}{2}''$, see Fig. 6 *h*). A few specimens are equipped

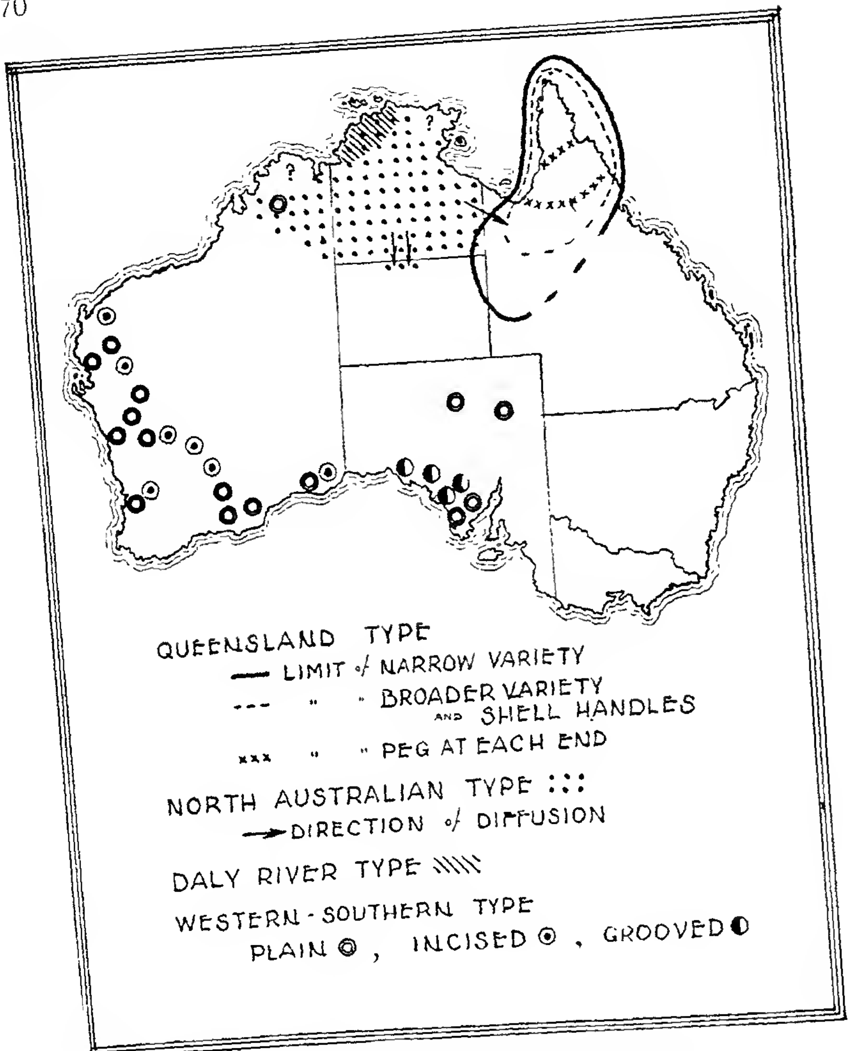

Fig. 5. Distribution of lath-like spearthrowers.

Queensland Type (Fig. 6 *k*)

Long and Narrow with One Peg.—SAM—Cairns, Herberton. AM—Dunk Is., Charlotte Bay, Clonagh, Burke Dist., Boulia, Gregory Dist., Austral Downs. Roth, Bull. 13, pp. 199–200. Coastal region, Bloomfield R. to Cape Grafton, Lower Tully R.

Long and Narrow with Peg at Each End.—SAM—Flinders R. to Etheridge R., Cooktown to Gulf, Muldira to Croyden.

Long and Narrow with Shell Grip.—SAM—Croyden. AM—Pennyfather R., Charlotte Bay. Report Cambridge Ex., IV, p. 196, Muralag to Mabuiag. North-western district (shells for handles traded from Gulf. Roth, 1897, p. 149. For methods of attachment see Roth, 1897, p. 198, Bull. 13, pp. 199–200.

with a projection peg at each end. A second variety, 2 to 5 inches in width, which also serves as a defence weapon to deflect spears, occupies a more restricted but also a widespread distribution within the area of the narrow form (Fig. 5). A third variety, localized to the coast between the Bloomfield River and Cape Grafton, is characterized by a curved rather than a straight shaft.[1]

The Queensland spearthrower is unique in that its projection peg lies in the same plane as the surface rather than arising from it at an acute angle as in other types. Air resistance, therefore, must be very little.

A feature of many specimens is a grip consisting of two shells, one on each side, attached by gum. From the Boulia

Medium Width with Shell Grip.—SAM—Batavia R., C. York.

Broad with No Shell.—AM—Batavia R.

Broad with Shell Grip.—AM—Batavia R., Staaten R., Normanton, Clonagh, C. Bedford.

Plain Curved Shaft.—SAM—Cairns. Roth, Bull. 13, p. 199, Bloomfield R. to C. Grafton.

North Australian Type (Fig. 6 *c, d*)

WAM—East and West Kimberley, Isdell Ra. SAM—Forrest R., Pine Cr., Darwin, Daly R., Katherine R., Powells Creek, Daly Waters, McArthur R., Alligator Rs. AM—Adelaide R. UP—Victoria R., Port George IV (Love, p. 25). Basedow, 1907, Coast south of Darwin. Spencer, 1914, p. 376, Common, Barrow Cr. to northern coast; 1928, p. 571, seldom traded south of Warramunga. Roth, Bull. 13, p. 201, traded to Burketown from west. Tindale, 1925, Pl. IX, Groote Is. (variant).

Western-Southern Type (Fig. 6 *e–g*)

Unincised.—WAM—Kimberley, E. Kimberley, Gascoyne, Murchison, Yalgo, Israelite Bay. SAM—Nannine, Geraldton, West Coast of South Australia, Gawler Range, Fowlers Bay, Eucla, Lyons R., Kopperamanna, Penong, York, Barrow Ra. Helms, Pl. XIV, No. 2, Fraser Ra., Hampton Plains; p. 269, Warrina. Schürmann, pp. 3, 213, Port Lincoln. UP—Peak Hill, Vasse, Bridgeton, Ajana, Mordicup, Mordiarup.

With Crude Flutings.—SAM—West Coast of South Australia, between Fowlers Bay and Streaky Bay, Denial Bay, Coopers Creek, Kopperamanna.

With a Longitudinal Zigzag Incised Ornamentation on Face.—UP—Lawlers, Albany, Cue, Maninga Marley. WAM—Ashburton, Geraldton, Eucla, Murchison. SAM—York, Lyons R., Meega Dist. Helms, Pl. XIV, No. 3, 4, Murchison; p. 272, similar to Fraser Ra.

Daly River Type (Fig. 6 *a, b*)

SAM—Port Essington, Daly R. NMV—Kakadu. AM—Alligator R., Wildman R. Basedow, 1907, pp. 34–35, Coast south of Darwin.

[1] It should not be regarded as having been derived from a boomerang for not only is the latter not found in this region but the boomerangs present further south in Queensland are quite different in form.

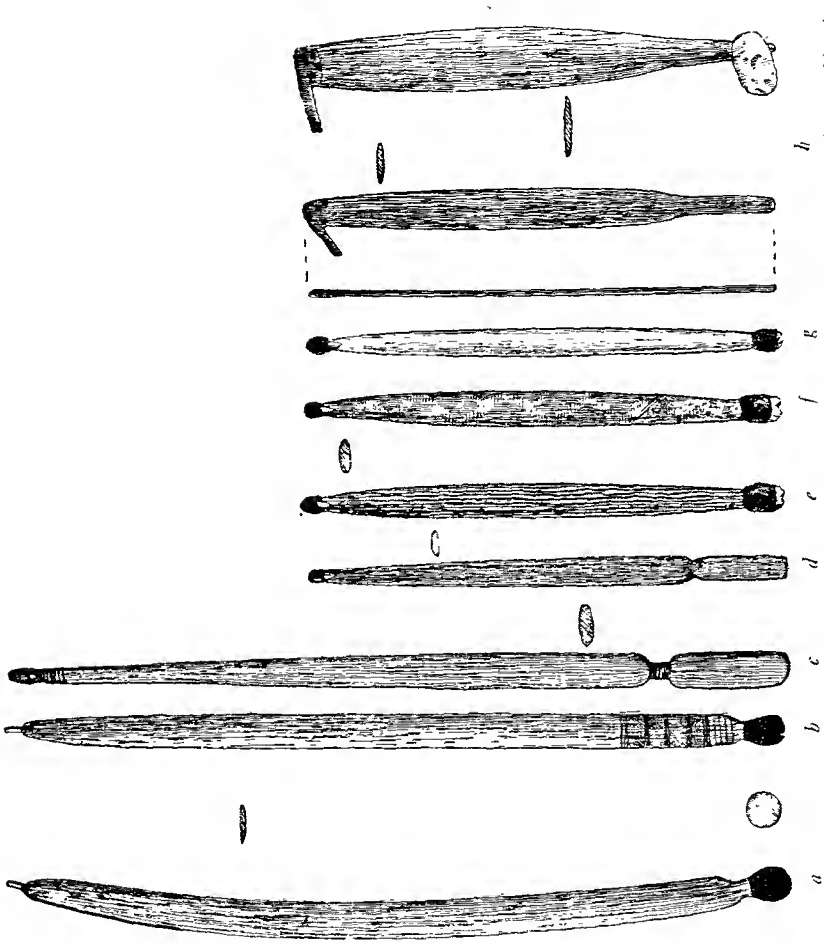

FIG. 6. Lath-like spearthrowers. *a*, *b*. Daly River type (After Basedow). *c*. North Australian type (UP). *d*. Groote Island variant (After Tindale). *e–g*. Western-Southern type. *e*. Fluted, widespread in South Australia (SAM). *f*. Incised, widespread in Western Australia (After Helms). *g*. Plain, widespread in South Australia and Western Australia (SAM). *h*. Queensland type (After Roth).

area to Cape York these shells are associated with both narrow and wide varieties but not all specimens in any locality are so equipped. Plain handles not only are common throughout this distribution but also appear further to the south and southeast. It would seem that the shell handle originated in the Cape York Peninsula. At least, we know that shells are traded southward by the Karunti tribe in the Normanton area to the Nouun tribe at Mullangera where they are passed on to the northern Mitakoodi and other tribes of northwestern Queensland.

North Australian Type.—This type of spearthrower is characterized by a narrow softwood shaft up to 4 feet or more in length (Fig. 6 *c*). A notch cut in each side near one extremity gives a handle appearance but since the shaft usually is grasped a few inches above this constriction it seems to lack practical significance. Gum handles and stone adze blades are lacking. This type seems to be used principally with the long, composite spear with a wooden or bamboo shaft.

It seems reasonable to believe that this type of spearthrower is of local development in North Australia where its distribution is centered. We know that it is being traded eastward to Queensland and southward into northern Central Australia. Presumably diffusion or trade, or both, are responsible for its appearances in the adjacent portions of Western Australia. On Groote Island a variant is found (Fig. 6 *d*).

Daly River Type.—Extremely thin, straight or slightly curved lath-like spearthrowers are found in the Port Essington-Alligator Rivers-Daly River region (Fig. 6 *a*, *b*). They are relatively long (about 4 feet) and plano-convex in cross-section. The round knob handle of moulded wax or gum is unique for this part of the continent. Apparently this type is a variant of the North Australian form but such a derivation cannot be established at the moment.

Western-Southern Type.—A most important spearthrower but one which seldom has been mentioned or figured is found

in the extensive area between Coopers Creek, South Australia, and the Gascoyne district of Western Australia, if not also in the Kimberley district. Made of hard wood, it is relatively long (up to 3 feet 6 inches) and bi-convex in cross-section (Fig. 6 *e–g*). Usually there is a gum handle which often contains a stone blade or a tooth knife.

Three varieties can be distinguished according to whether the surfaces are (1) plain, (2) crudely fluted, or (3) incised with the longitudinal zigzag design. The plain specimens seem to be the most widespread. The fluted examples apparently are limited to South Australia (Eyres Peninsula and Coopers Creek). The very narrow forms with incised decorations, similar to those in the broad spearthrowers, seem to be widely scattered in Western Australia from Eucla to the Gascoyne.

Since in many instances it is impossible to decide whether a specimen should be classified with the broad leaf-like forms or with the narrow types the question arises as to their possible historical relationship. Although there are many examples which could be regarded as transitional we have no direct chronological evidence of the development of one type from the other. Geographical distributions, however, do suggest that the lath-like type is the older since it is now found only in areas on the periphery of the broad forms. Since the latter apparently developed in the western half of Australia, its forerunner may have been the Western-Southern narrow type. Present evidence permits us only to point out this possibility.

The three main lath-like spearthrowers may have no direct historical relationship in respect to their similarity in form. The Queensland and North Australian types now adjoin one another but this contiguity is recent and the result of the eastward diffusion of the latter.

The North Australian and Western-Southern types may overlap in the Kimberley district, but this is uncertain. We cannot conclude that they are or are not independent developments until we know what type of spearthrower preceded the

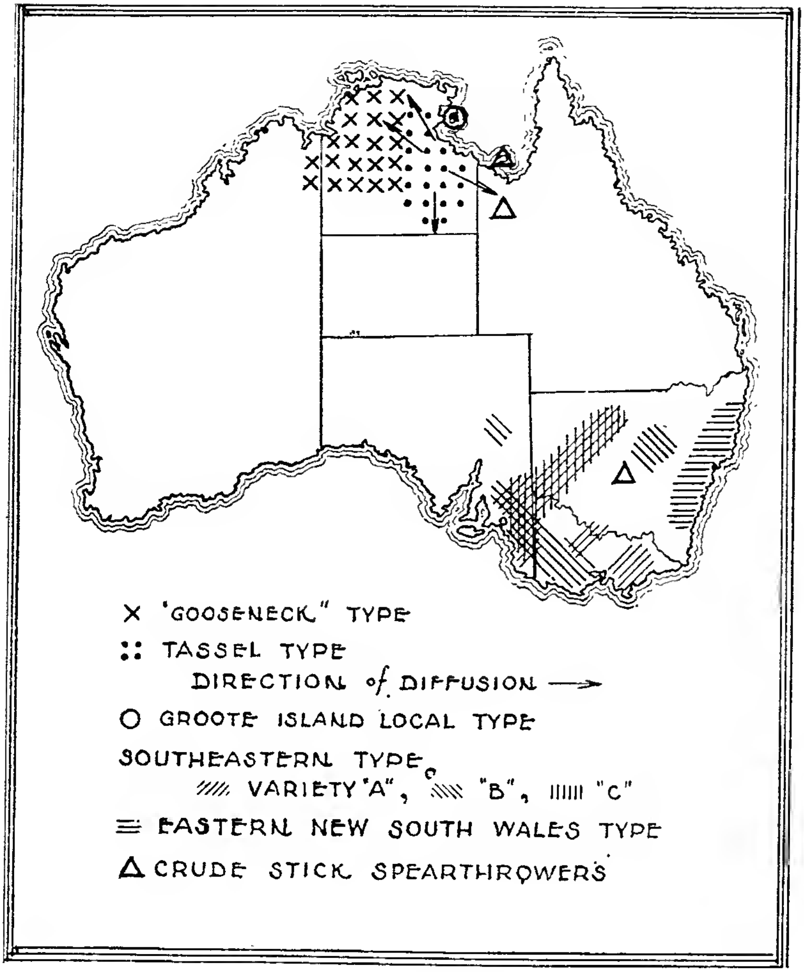

FIG. 7. Distribution of stick-like spearthrowers.

Tassel Type (Fig. 8 *d*).—SAM—Tennant Creek, Borroloola, McArthur R., Katherine R. Roth, Bull. 13, pp. 200–201, Burketown (traded from west). Spencer and Gillen, 1904, pp. 669–670, Tjingilli, Umbaia, Gnanji, East to Gulf. Spencer, 1928, II, p. 571, manufactured particularly by Umbaia and Gnanji; fig. 412, Anula; 1914, p. 377, traded to northern tribes along coast of Gulf of Carpentaria. Davidson, Fieldnotes, not made at Katherine R. Basedow, 1907, p. 36, rare among Larakia, Wogait. Macgillivray, I. p. 147, Port Essington (1852). *Specimens lacking the Tassel.* SAM—Tennant Creek, Daly R., Katherine R., Borroloola. AM—Burketown, Queensland—North Australia border. On Groote Island this type is bound with fiber string but no tassel is employed. Tindale, 1925, p. 99.

Gooseneck Type (Fig. 8 *a*).—SAM—Alligator R., Daly R., Daly Waters., Victoria R. Davidson, Fieldnotes, Katherine and Victoria Rs. WAM—Kimberley. Basedow, 1907, pp. 34–35, Larakia, Wogait, Berringin. AM—Port Essington, Elsie R. (with wooden peg). NMV—E. Kimberley.

Southeastern Types.—See fig. 9.

broad forms in the central and western regions. It is conceivable that the differences in the two lath-like forms may be the result of the different types of wood employed and that they represent divergences from a common prototype. On the other hand their similarity in general form may be the result of convergent developments in different areas from a common ancestor or from different forms.

3. *Stick-like Spearthrowers*

Stick-like spearthrowers are found in two areas in Australia (1) the Southeast and (2) North Australia and adjacent Queensland, including the Wellesley Islands (Fig. 7).

North Australia and Northwestern Queensland

Tassel Type.—This spearthrower consists of a stick-like shaft to which a fringe or apron is attached to an encircling ridge near the butt (Fig. 8 *d*). Since the shaft is grasped above the place of attachment the fringe does not interfere with the weapon's use. The distribution is centered in southeastern North Australia where these spearthrowers are manufactured principally by the Umbaia and Gnanji. Specimens are traded southward to beyond Tennant Creek and eastward to Burketown, Queensland. It is known that trade has occasionally brought these articles to the coast of North Australia for almost a century.

Groote Island Local Type.—A spearthrower with a similar round shaft but with a wide flaring lanceolate handle is made only on Groote Island (Fig. 8 *c*).

Wellesley Islands Type.—This is the crudest and simplest spearthrower of Australia and is no more than a plain stick with the projection peg carved in the solid (Fig. 8 *e*). Some specimens have been reported for the adjacent mainland. Comparison should be made with some of the forms in the Southeast (Fig. 9).

Gooseneck Type.—The "gooseneck" spearthrower is narrow, round in cross-section, very light in weight and about four feet in length (Fig. 8 *a*). At one end a lump of gum is

molded to a blunt point in lieu of a wooden projection peg; at the other extremity a coating of gum extends to a circumscribing ridge of the same material several inches up the shaft. The known distribution of this type is centered in northwestern North Australia and adjacent Western Australia.

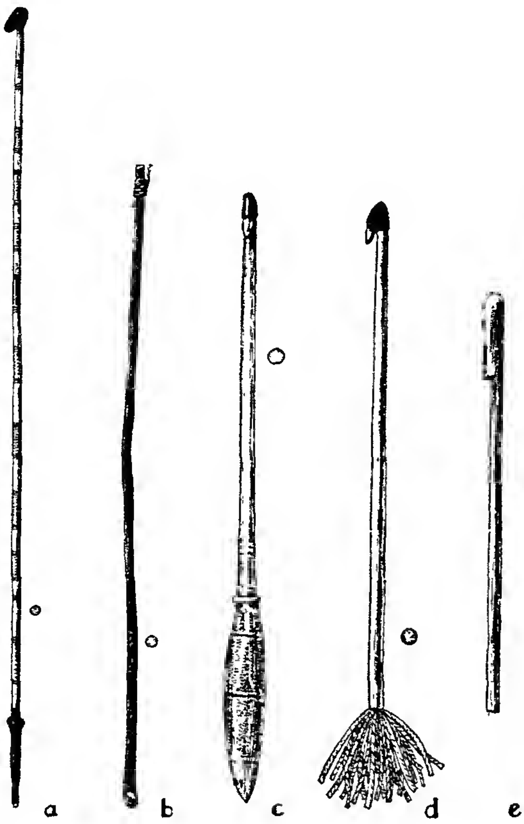

Fig. 8. Stick spearthrowers. *a, b.* Wardaman (North Australia), *b* for children (UP). *c.* Groote Island (After Tindale). *d.* Tassel type (After Roth). *e.* Wellesley Islands (After Roth).

It seldom is found south of Daly Waters, and we are not certain that it is made in the latter locality. Since this type is used exclusively with the light-weight reed spears its

development presumably is more recent than the appearance of these spears in this region.[1]

Southeastern Australia

In Southeastern Australia, that is, New South Wales, Victoria and South Australia east of Spencer Gulf, the spear-

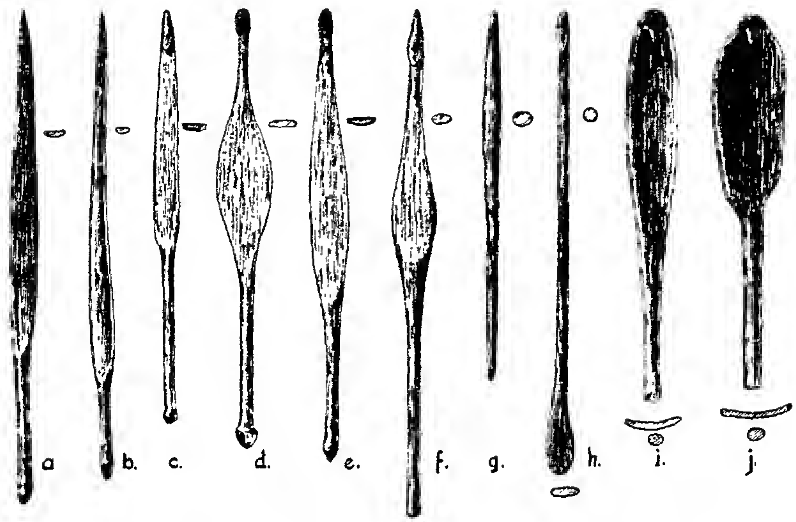

FIG. 9. Spearthrowers from Southeastern Australia (SAM).

a–c. Peg carved in the solid. SAM—Narrinyeri, Lower Murray R., Bourke. Howitt, p. 277, Kurnai

d. Attached peg (of wood unless otherwise noted). SAM—Point McLeay (or tooth), Bogan R., Adelaide (tooth), Murray R., Eurowie. Cawthorne, p. 5, Adelaide. (Cf. Angas, Pls. 10, 22.)

e. Attached peg. SAM—Mannum, Lower Murray, Point McLeay, Coorong, Eurowie. Cawthorne, p. 5, Adelaide. Bretton, plate facing p. 285, New South Wales (locality not given). Dawson, p. 87, Western Victoria. NMV—Lake Callabonna.

f. Peg carved in the solid. AM—Dubbo. SAM—Narrinyeri, Lower Murray.

g. SAM—New South Wales.

h. SAM—Modern La Perouse. AM—Northern Coast of New South Wales, MacLeay R. Bretton Plate I; Saturday Magazine, No. 252, p. 217; Flanagan, pp. 80–81, give New South Wales. Localities are not specified but probably are eastern or coastal. One specimen in NMV is labeled "Probably from far interior." A less flaring handle is shown by White, J., plate facing p. 292. Compare with Peron, Pl. 22. Both apparently coastal. Each has a shell gummed or tied to handle extremity.

i–j.—SAM—Eurowie, N. S. W.

[1] Specimens with a fiber binding but without the fringe are made on Groote Island. Others, lacking the fringe, have been collected at Tennant Creek, Burketown and the Daly River region, but it is not certain but that these originally had tassels attached. Indeed many specimens now lacking tassels obviously had been equipped with them.

throwers comprise a distinctive group. Several varieties can be distinguished but there is considerable overlapping and often it is difficult to assign individual specimens to one variety or another. Typical examples are shown in Fig. 9. Although the shafts of several are round in cross-section throughout their length most specimens are characterized either by a flattening on the face, or a flare on each side of the shaft, or by both. The handle extremity may be a plain point, a small knob carved in the solid or, most rarely, a gum knob. The use of an adze blade in the gum knob seems to be lacking.

Another interesting feature is the use in many specimens of a peg carved in the solid, a trait apparently lacking elsewhere in Australia except in the Wellesley Islands and the adjacent mainland. Some specimens of each variety have affixed pegs of wood, as elsewhere on the continent, or of bone or tooth, materials seldom used in other regions for this purpose.

It is convenient to divide these spearthrowers into three main varieties. A fourth seems to show influence from Central Australia.

A. The first, characterized by a flattened surface on the face and a swollen shaft which tapers gradually toward the peg end and abruptly to the handle end, was used formerly along the Darling River from near Bourke to its confluence with the Murray and from Gippsland to the Coorong District of South Australia (Fig. 9 *a–c*). Tooth or bone pegs seem to be associated only within South Australia.

B. A second variety, somewhat similar to the first but with the flare in the shaft tapering gradually toward each extremity (Fig. 9 *e, f*) occupies the same distribution in South Australia whence its use extends to western Victoria and central New South Wales.

C. The spearthrower with the unusual shelf-like projection at the middle of the shaft (Fig. 9 *d*) apparently is restricted to the Lower Murray River and along the Darling River as far as Bourke.

D. The fourth variety is similar to the others in respect to

the round shaft at the handle end but corresponds to the Central Australian type in the wide concave upper surface at the forward extremity of the weapon (Fig. 9 *i*, *j*). Since this variety has been found only in the Eurowie district of western New South Wales it seems not unlikely that influences from the west are responsible for the peculiar shape.[1]

Eastern New South Wales.—In coastal New South Wales and possibly inland, although this is most uncertain, there formerly was present a local type of spearthrower characterized by a round stick-like shaft and a wide flat handle (Fig. 9 *h*).[2] Some old specimens were equipped with a shell fastened at a narrower handle extremity. The wide handles are said to have been used occasionally as canoe paddles, a not incredible function since a common local method of canoe propulsion was with the aid of two small pieces of bark, one held in each hand.

The appearances of crude stick-like forms and of projection pegs carved in the solid in the Southeast and in northwestern Queensland suggest (1) that there is a close historical relationship between the spearthrowers of these regions and (2) that they diffused through the intervening region. Hence it seems not unlikely that these primitive forms were formerly present, if not the most recent type, in the positive localities in southern Queensland and that they have been replaced in most of northwestern Queensland by the Queensland lath-like form which seems to have spread from the Cape York Peninsula. In view of its simplicity it also seems permissible to suspect that some basic stick-like form may have been the earliest in Australia from which the others have been developed. Such

[1] The question of influences from the west is complicated by the lack of satisfactory information from the intervening area of northeastern South Australia. The Wonkonguru generally do not manufacture spearthrowers but it is important to note that the specimens they occasionally make are said to be the results of Arunta influences. Among the Wailpi (Flinders Ranges) spearthrowers, formerly thought to be lacking, are now known to be present but seldom employed, the natives preferring javelins and throwing-clubs. The local type is not described.

[2] Sollas, p. 270, following Von Luschan, p. 141, classifies this type with the typical North Australian lath-like spearthrower but this seems most unwarranted in view of the important dissimilarities in their shapes and cross-sections. There is greater resemblance with the Groote Island local type (Fig. 8 *c*).

an inference does not imply that similar crude spearthrowers were at one time widely distributed on the continent. Such may have been the case but we have no evidence at present to show from what prototypes the various lath-like and paddle-like forms were directly developed. Furthermore some of the most advanced forms may have been the first spearthrowers to diffuse into certain regions.[1] However since both the paddle-like and lath-like types seem quite obviously to be elaborations of some more primitive form, their ultimate ancestor may be some crude stick-like type such as is still found in the East. It is interesting to note that the *modern* New Guinean spearthrower is stick-like in proportions but "female," made of bamboo, and characterized by some details not found in Australia, for instance, the peculiar grip fastened to the upper side of the weapon (Fig. 10). It also is fitted

FIG. 10. Modern New Guinean spearthrower (SAM).

differently to the spear for the concavity is not placed at the butt but to a projection peg secured to the shaft of the spear near its middle.[2] What the earliest spearthrower in New Guinea may have been like we have no evidence to demonstrate at the moment.

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[1] It is interesting to note that the method of holding the spearthrower seems to be the same throughout the continent regardless of the type of spearthrower employed. The shaft of the spearthrower is grasped between the index and middle fingers and the spear is held loosely by the index finger and thumb. Basedow, p. 35 (North Australia); Cawthorne, p. 5 (Adelaide); Hale and Tindale, 1933, p. 99 (Cape York Peninsula); Hammond, p. 35 (Southwest); Tindale, p. 134 (Groote Is.).

[2] Harrison, p. 36; Wirz, Pl. 36.

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MOLECULAR ROTATION IN SOLIDS

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(Read April 24, 1936)

Abstract

An alternating electric field with which the dielectric constant is determined has been used to investigate the possible rotation of molecules in solids. It had previously been known that molecules in solids vibrate in very short paths about points in a rigid lattice and specific heat measurements had indicated that, in a few solids, the molecules begin to rotate as the temperature rises. The dielectric constant measurements provide a means of reaching into the material, taking hold of any positive and negative electricity on opposite sides of the molecule and learning whether it can turn. A number of molecules have been found to turn as easily in the solid as in the liquid until falling temperature reduces their energy so far that they rather suddenly cease to turn. Some, at least, of the H_2O molecules are found able to turn in ice for some distance below its melting point and the small heavy molecules of arsine are just losing their freedom of rotation at a temperature only 20° above the absolute zero. If one could actually see the molecules in the interior of the material, the only difference between the solid and the liquid would be that the points about which the molecules are vibrating would be fixed in the solid and wandering about slowly in the liquid. To such an observer, the difference between a solid and a liquid would be trifling.

The division of matter into the solid, liquid and gaseous states has always been recognized, but as is customary with most sharp divisions in science, continued investigation has dulled the sharpness. It was found that, at a certain critical temperature, a gas could be compressed until it was identical with the liquid at this temperature. Most liquids, on cooling, were known to solidify sharply at a certain temperature, the freezing point, into a definite crystalline form, evolving a definite quantity of heat on doing so. A few, however, were found merely to increase in viscosity on cooling and eventually to stiffen to a rigidity comparable to that of a crystal. Sometimes a gradual rearrangement of the molecules in this class into a definite crystalline structure occurred with the passage of time. Sometimes, the rearrangement was indefinitely postponed. A very few liquids consisting of large molecules were found to be anisotropic throughout a narrow region of temperature above the freezing point, presumably because

of a definite molecular orientation in this region. With change of temperature, many solids were found to undergo transitions, some of which involved change of crystal form as well as change of energy content, which accompanied all the transitions.

In the familiar terms of the kinetic theory, the molecules in a gas are distributed and oriented wholly at random, free to rotate, travelling at high speeds in all directions, the direction of motion being constantly changed by collisions. The molecules are known to be so far apart as to exert, on the average, only very slight attractive forces upon one another. Liquids were regarded as differing from gases only in that the randomly distributed and oriented molecules moving in all directions were so close together as to exert strong attractive forces upon one another. In a solid, the random translatory motion disappeared and the molecules, held by strong forces, vibrated about points fixed in a pattern, the result of which was the crystal form. In the glasses, the pattern had not yet been established.

About twenty-five years ago, X-ray analysis showed that the crystal pattern was an actual lattice formed of ions or molecules, a variety of arrangements being possible. Recent X-ray work points to the existence of a roughly lattice-like distribution of the molecules in liquids. Now, if one thoroughly shakes a box half full of billiard balls, they will fall into an arrangement of closely packed spheres. The arrangement of closest packing corresponds to that found in the hexagonal crystal system, in which the atoms of twelve metals are arranged. The next closest possible packing of spheres gives the arrangement found in the face-centered cubic lattice in which the atoms of twenty-one elements crystallize. In view of the fact that the molecules in a liquid are almost as close together as those in a solid, mere limitation of space might be expected often to necessitate a more or less regular molecular arrangement.

The old picture of the liquid state must, therefore, be modified. The molecules have some regularity of arrangement and because of the strong forces, acting upon them,

may vibrate about equilibrium positions as in a solid, the equilibrium positions themselves tending to migrate slowly (P. Debye, *Physik. Z.*, **36**, 100, [1935]) as shown by molecular diffusion. Rotation of the molecules cannot now generally occur with freedom since many of them will not possess sufficient thermal energy to overcome the potential energy of their orientation in the strong force fields of their neighbors, but will execute a rotatory oscillation, which increases with rising temperature. The rotation discussed in this paper is always one in which an actual translation of atomic nuclei occurs, any other being unimportant.

When a substance is placed in an electric field, the charges in each molecule are slightly displaced to form a dipole which gives rise to a small dielectric constant for the substance. If, in addition, the molecules are normally electrically unsymmetrical, thus possessing permanent dipoles, they tend to turn so as to orient their dipoles in the field, giving a much larger dielectric constant, which depends upon the size or moment of the dipole and the ability of the molecule to orient in the field. Measurements of dielectric constants thus provide a means of determining the freedom of polar molecules to turn. For example, nitrobenzene, the molecule of which has a large dipole moment, shows a smaller dielectric constant in proportion to the molecular concentration in the liquid state than in the gas because of reduction in the freedom of molecular rotation. With falling temperature, the dielectric constant rises because of the decrease in thermal agitation of the molecules. Solidification eliminates freedom of molecular rotation and the dielectric constant, accordingly, drops to about one-tenth of its value for the liquid. When water solidifies, the H_2O molecules, which are strongly associated in the liquid, do not at first completely lose freedom of rotation in their hexagonal lattice. Indeed, the dielectric constant of ice near its melting point behaves like that of a very viscous liquid, the molecular freedom being greatly reduced but not wholly eliminated. It is rather startling to find evidence of so much motion in a solid familiar in its hardness and rigidity. It is, perhaps, more startling to find

little or no loss of rotational freedom when the analogous hydrogen sulfide solidifies at 187.7° K. The dielectric constant of the solid is greater than that of the liquid because of its greater density and increases with falling temperature as would that of a liquid until freedom of rotation ceases at 103.5° K. The rotating H_2S molecules form a cubic lattice, which has not been investigated below the temperature where rotation ceases. Hydrogen chloride may be mentioned among many other molecules showing similar behavior. The rotating molecules of the solid form a cubic lattice, which changes to the less symmetrical orthorhombic when rotation ceases at 98.9° K. The dielectric constant of arsine just measured by Mr. S. A. McNeight at Princeton is higher for the solid down to 20° K. than for the substance in the liquid state, showing that the heavy AsH_3 molecule still has some freedom of rotation even at this extremely low temperature. The diatomic hydrogen molecule is the only one previously found to rotate below this temperature.

Since rotation must increase the symmetry of the field or effective shape of the molecule, we should expect it to make the lattice tend toward that given by close-packed spheres. Actually, out of thirteen solids with rotating molecules for which X-ray data are available, twelve have hexagonal or cubic lattices. The thirteenth, hydrogen iodide, has a tetragonal lattice, which does not undergo rearrangement when rotation ceases. Frequently, when rotation ceases the lattice becomes less symmetrical. Since the energy of a molecule is less dependent upon its orientation in a lattice of high symmetry, the molecule should rotate more easily in such a lattice. It may often happen, however, that the molecules are spaced too closely to permit of rotation of a long axis as, for example, in the cubic lattice of carbon dioxide.

It has been found from specific heat measurements, which give less direct evidence of molecular rotation than does the dielectric constant (Cf. K. Clusius, Z. Elektrochem., **39**, 598, [1933]) that the energy absorbed by a solid when molecular rotation sets in lies between 3 per cent and nearly 100 per cent of

the heat of fusion. The energy content of a solid with rotating molecules just below the melting point commonly differs from that of the liquid just above the melting point by little if any more than it differs from that of the solid below the temperature where rotation sets in.

We must now picture the molecules of a solid at low temperature as not only vibrating in short paths about points fixed in a lattice but also executing rotational vibration about their individual centers of gravity, the energies of both types of vibration increasing with rising temperature. The rotational oscillation of the molecule is about an orientation of minimum potential energy. If the difference in energy between this minimum and the maximum attained during a complete rotation of the molecule is equalled by the rotational energy of the molecule before the melting point is reached, the molecule commences to rotate in the solid. If the potential energy barrier is too high, the molecule cannot rotate until the increasing translational vibrations of the molecules break down the lattice and liquefaction occurs. Rotation or non-rotation in the liquid then depends upon the energy possessed by the molecule and the positions and orientations of the neighboring molecules, which determine the height of the potential barrier to be passed in rotation, some molecules being in rotation at any given instant, others merely oscillating. The setting in of molecular rotation in the solid may occur rather gradually because of the unequal distribution of energy among the molecules, arsine, for example, showing an increase of rotation from 20 to 32.1° K., but commonly the accompanying transition occurs almost as sharply as melting because of the weakening of the intermolecular forces in the neighborhood of a molecule which has begun to rotate. Evidently, the difference between a solid and a liquid is still further reduced by the facts which have been enumerated. Viewed microscopically, the only difference is the slow migration in the liquid of the molecular equilibrium points, which are fixed in the solid.

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FURTHER EXPERIMENTS ON THE MASS ANALYSIS OF THE CHEMICAL ELEMENTS *

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(*Read April 25, 1936*)

ABSTRACT

Further experiments have completed the preliminary analysis of the isotopes in all the chemical elements. New isotopes not previously reported have been found in cerium and barium. Exact comparisons show that the usually accepted atomic masses of uranium and thorium are too high and should be 238.090 and 232.070. The masses of the lead atoms into which these elements are transformed by radioactive disintegration have been observed, and compared with the values calculated from the particles emitted during these radioactive transformations. Agreement is found only after the mass equivalent of the energy of these particles is allowed for.

In a paper published in the *Proceedings of the American Philosophical Society* for December, 1935, I described a mass spectrograph and gave examples of the analysis of the isotopes of the chemical elements.[1] A novel feature of the apparatus is a new type of source, which allows the use of solid electrodes; another is the use of a new type of focusing that brings to a focus a divergent beam of charged ions, even when it contains ions of slightly different energies. In that paper several examples were given of the analysis of elements which had baffled all previous attempts to study them in the gas discharge. It was also found possible to obtain a greater resolving power than had been used previously by Dr. Aston.

During the last six months many elements have been examined and approximately 140 isotopes belonging to 48 elements have been observed. I shall first discuss the general arrangement of the isotopes of the chemical elements as it now appears, and then describe the progress that is being made in the exact comparison of the masses of the atoms.

* This investigation was supported by a grant from the Penrose Fund of the American Philosophical Society.

[1] *Proc. Amer. Phil. Soc.*, LXXV, p. 755, 1935.

The apparatus is described in the paper referred to. In some of the present experiments the slit was narrowed to 0.02 mms., and under good conditions images were obtained on the photographic plate approximately 0.025 mms. in width giving a resolving power of approximately 4000. The difficulties with unsharp lines mentioned on p. 764 of that paper have been traced to dust particles on the pole faces and have been eliminated. An example of the mass spectrum of molybdenum is shown in Pl. A I.

Present Status of the Analysis of the Elements

The present status of the analysis of the elements is summarized in Fig. 1. The isotopes of the elements are given in horizontal rows. We may think of the ordinates as representing the number of protons in the element and the abscissæ the number of neutrons in the different isotopes. This theoretical interpretation suggested by Heisenberg[1] gives a convenient basis for the graphical representation. The new isotopes are represented by open circles and it is seen that all of the known elements have now been subjected to analysis. The dots represent previous observations largely due to Aston. In the cases where a circle surrounds a spot, the existence of this previously known isotope has been confirmed in the present experiments. Of the *140* isotopes observed, *116* confirm Aston's results and *24* are new ones.

It is of interest to note that the table has some suggestions of order. The lines drawn in above and below certain groups give the limits of stability of the nuclear structures and support the theories of Guggenheim[2] and Elsasser[3] on the way the nuclei are built up. The new isotopes of cerium[4] and barium are of particular interest in this connection.

[1] W. Heisenberg, *Zeit. f. Phys.*, **77**, 1, 1932.

[2] K. Guggenheim, *Journ. de Phys.*, **5**, 253, 1934.

[3] W. M. Elsasser, *Annales de l'Institut Henri Poincaré*, V, p. 223, 1935.

[4] The author is indebted to Professor B. S. Hopkins for the sample of pure cerium oxide. The very faint mass shown at 141 may be due to a possible trace of praseodymium.

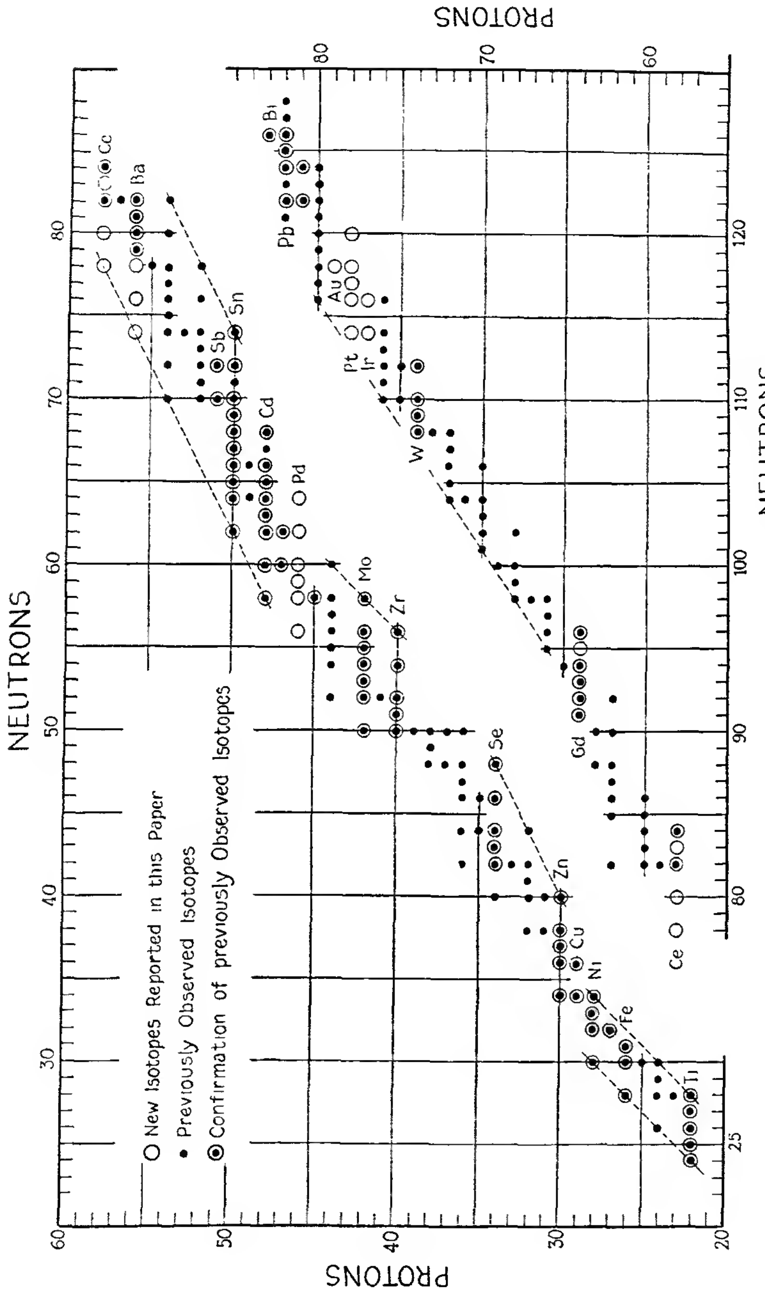

Fig. 1. Table showing isotopic constitution of the chemical elements.

The Exact Comparison of Atomic Masses

One valuable feature of the spark sources that have been developed for use in these experiments, is the production of ions with 2, 3, 4, or more unit charges in addition to the singly charged ions. An ion with two charges moves in the same path as a singly charged ion of half the mass. In this way it is possible, for example, to bring tungsten ions of mass 184 into coincidence on the photographic plate with zirconium ions of mass 92. When this is done with the resolving power used in these experiments, it is found that the coincidence is not exact but that the doubly charged tungsten ion lies alongside the singly charged zirconium ion. This "packing effect" or divergence of the atomic mass from exactly integral values (taking oxygen 16 as exactly 16) has been observed by Dr. Aston in many cases. In Fig. 2 we have a curve giving the

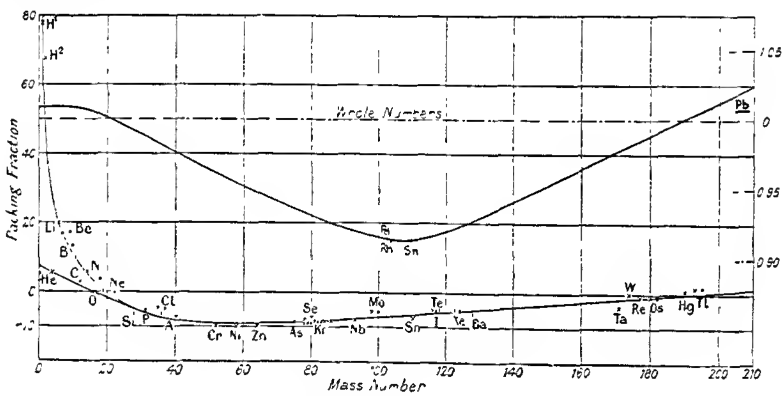

Fig. 2. Aston's packing fraction curve.

divergence from an integral value for the elements observed by him.[1] Our knowledge in this field remains very incomplete as three quarters of the isotopes have not as yet been measured, and it is a field where increased accuracy is very desirable. We would like very much to know whether the isotopes of one element differ in mass by exactly one unit or by multiples of the mass of the neutron 1.008. It would be of interest to see whether the elements that absorb neutrons

[1] F. W. Aston, *Mass Spectra and Isotopes*, p. 167, Longmans, Green & Co., 1933.

strongly have isotopes that differ in mass by that of one neutron, possibly corrected for the energy of any gamma rays emitted; also whether the packing fraction curve is a smooth curve or shows irregularities at certain places; finally, whether the emission of energy in the continuous β ray spectrum is associated with mass changes.

I shall illustrate this development by showing the comparison of doubly charged uranium (238) and thorium (232) atoms with singly charged tin ions of masses 119 and 116. Tin was the lower electrode in a spark in which thorium or uranium was the upper. Pl. A II and III show that the uranium ion at 119 and the thorium ion at 116 are heavier by 0.131 and 0.120 mass units respectively. If we take Aston's values for the tin isotopes, the masses of the uranium and thorium isotopes come out as 238.090 and 232.070 respectively. We must conclude that the chemical atomic weights 238.14 and 232.12 are too high.

An interesting comparison may be made with the mass of lead into which both of these elements are finally transformed by radioactive disintegrations. The masses of the lead isotopes were found by comparing the doubly charged lead ions, of masses 204, 206, and 208, with singly charged rhodium ions at 103 and palladium ions at 102 and 104, as illustrated in Pl. A IV and V. The differences amount to 0.086. The masses of the palladium and rhodium isotopes have not been measured directly. From the upper curve in Fig. 2, we would expect them to be about 0.085 units less than exact integers. Taking 0.085 for rhodium and palladium, we find the masses of the lead isotopes only 0.002 units above the integers 206 and 208. These values are definitely below Dr. Aston's curve as indicated in Fig. 1 and are subject to correction in case later direct measurements show that rhodium and palladium diverge considerably from Dr. Aston's curve.

It is of interest that these provisional values give almost exact agreement with the masses that we should expect for lead formed from uranium or thorium by radioactive transformation. In Fig. 3 the four lines A, B, C, D are the meas-

ured mass differences used in finding the values for uranium, thorium and lead. On the right is plotted the mass differences expected from the loss of 8 helium atoms and 6 β-rays in the case of uranium, and 6 helium atoms and 4 β-rays in the case of thorium, taking Aston's new value 4.0039 for the mass of helium. It is evident that agreement is only obtained by taking into account the mass equivalent of the large amount

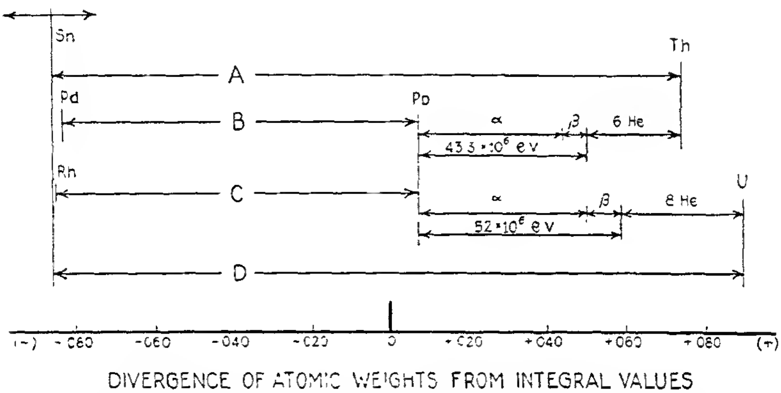

FIG. 3. Diagram showing the agreement of the observed divergence of the atomic masses of uranium and thorium with the values calculated from the energy released in the radioactive transformations.

of energy emitted, 52.0×10^6 electron volts in the case of uranium, and 43.3×10^6 electron volts in the case of thorium. It is unfortunate that the accuracy is at present not sufficient to say definitely that the maximum energy of the β-rays as shown must be included, for the uncertainty in the relative values of the palladium, rhodium and tin masses is of the same order as the mass equivalence of the β-ray energies.

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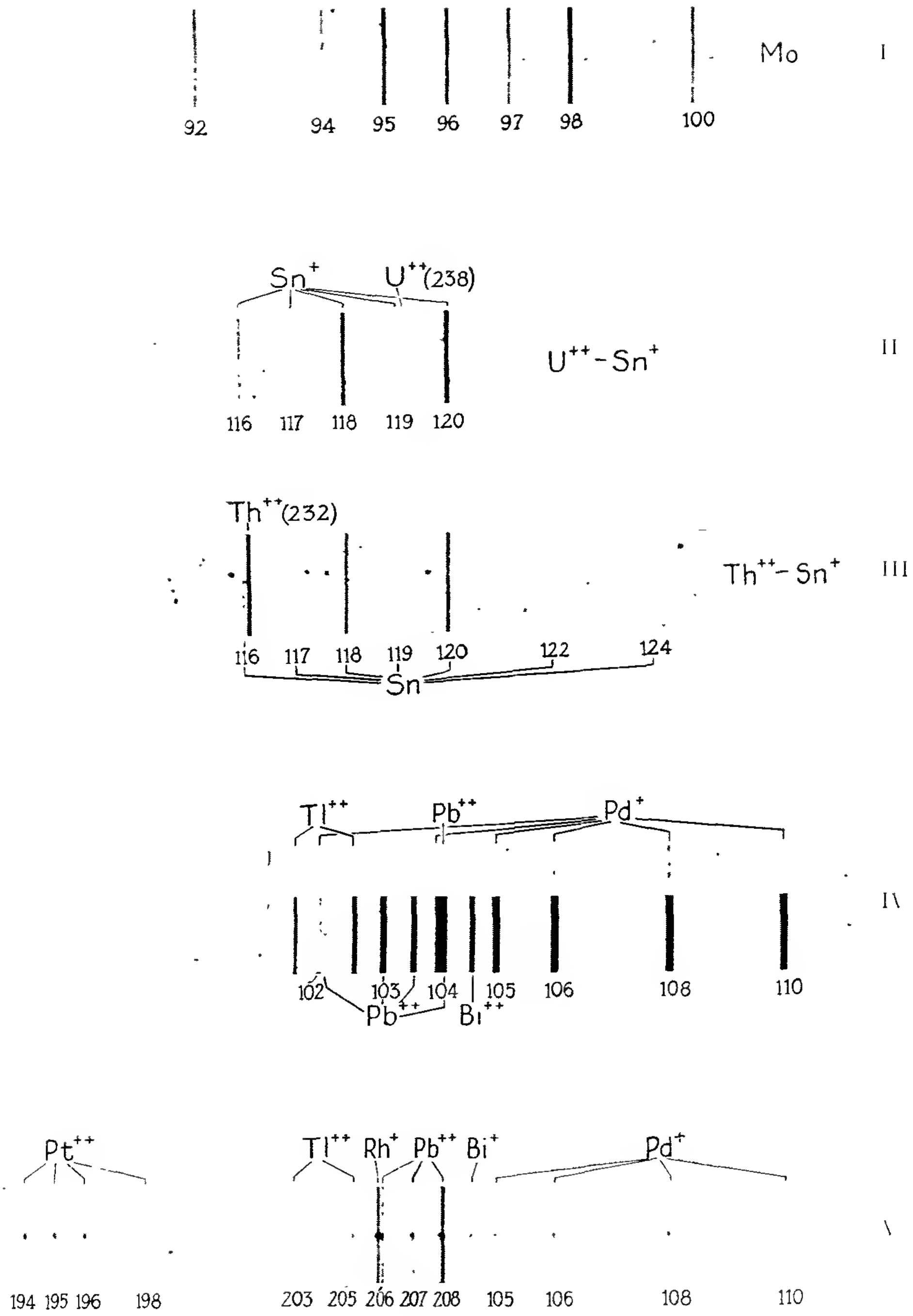
Mo
I
92 94 95 96 97 98 100
Sn⁺ U⁺⁺(238)
U⁺⁺-Sn⁺
II
116 117 118 119 120
Th⁺⁺(232)
Th⁺⁺-Sn⁺
III
116 117 118 119 120 122 124
Sn
Tl⁺⁺ Pb⁺⁺ Pd⁺
IV
102 103 104 105 106 108 110
Pb⁺⁺ Bi⁺⁺
Pt⁺⁺
Tl⁺⁺ Rh⁺ Pb⁺⁺ Bi⁺ Pd⁺
V
194 195 196 198
203 205 206 207 208 105 106 108 110

PLATE A.

ON THE SPECTRUM OF NOVA HERCULIS

N. T. BOBROVNIKOFF

ABSTRACT

Absorption and fainter emission lines in the visual spectrum of the nova have been studied in detail. Among 150 measured absorption lines 88 have been identified and 62 could not be properly assigned to any element. The following elements were represented by spectral lines in the visual region: AlII, AlIII, CrII, FeI, FeII, H, MgI, NII, NaI, OI, SII, ScII, SiII, TiII, YII. The spectrum of the nova during January 1935 was compared with the spectra of B and A type stars. The greatest correspondence was found between the spectrum of α Cygni and that of the nova. The observations on the spectrum of the nova in the visual region made at other observatories were found to be in agreement with the writer's results. Many spectroscopic phenomena considered to be peculiar to Nova Herculis were shown to have been observed in other novæ.

INTRODUCTION

IN MY previous paper [1] on the spectrum of Nova Herculis a detailed study was made of the more conspicuous emission and absorption lines in the visual region. These included the lines, or rather wide bands, of H, [OI], FeII and Na. Reference was made to the numerous fainter absorption and emission lines measurable on some spectrograms. The present paper deals with these fainter lines in the visual region of the spectrum. Some general remarks have been added at the end of this investigation. The literature on Nova Herculis is rapidly increasing in volume and permits interestint comparisons to be made between results obtained at different observatories and with different instruments.

The observational material is the same as used in the first paper. The list of spectrograms is given in table 1 of the above mentioned publication.

The study of the sprectrum of the nova was greatly facilitated by a recent paper by R. K. Marshall [2] on the visual region of the spectra of early-type stars. The spectro-

[1] "The Spectrum of Nova Herculis in the Visual Region," *Perkins Observatory Contribution* No. 2, 1935. *Proc. Amer. Phil. Soc.*, LXXV, p. 717, 1935.

[2] *Ap. J.*, 82, 97, 1935.

grams for his work were obtained with the same instrument, the Perkins 69-inch reflector and autocollimating spectrograph, as those of the nova. All the stars studied by Marshall are of class B and A, and there should be a good correspondence between the spectra of these stars and the absorption spectrum of the nova.

For reference purposes the stars used by Marshall in his investigation are denoted with numerals as follows:

TABLE 1

Notation	Star	Spectrum
1	γ Orionis	B2
2	β Tauri	B8
3	β Orionis	B8p
4	α Canis Majoris	A0
5	α Lyræ	A0
6	α Andromedæ	A0p
7	ϵ Ursæ Majoris	A0p
8	α Cygni	A2p

Dunham's paper on the spectrum of α Persei [1] was also extensively used. The term notation, intensities and wavelengths were taken from Miss Moore's paper.[2]

Identified Absorption Lines

The difficulty of identification of the absorption lines in the spectrum of the nova is twofold. First, the presence of emission bands obliterates fainter absorption lines and introduces uncertainty into measurement. A space between two emission bands may appear as a spurious absorption line. Second, all absorption lines in the nova were displaced to the violet but by variable amounts. It is therefore impossible to feel certain in the identification of, say, two FeI lines one of which shows a displacement of 4.50 A while the other in the same neighborhood on the same plate shows a displacement of as much as 7.30 A. It is also evident that the lines in the nova did not behave in the same way as they do in the laboratory. Their relative intensity was sometimes quite different, so that the consideration of intensities in the same multiplet is of no great help in the identification.

[1] *Princeton Observatory Contributions* No. 9, 1929.
[2] A Multiplet Table of Astrophysical Interest, Princeton, 1933.

TABLE 2

IDENTIFIED ABSORPTION LINES

El	Laboratory λ	Laboratory Multiplet	Laboratory i	Δλ Nova Jan. 5.492	Δλ Nova Jan. 18.476	Δλ Nova Jan. 23.547	Δλ Nova Jan. 28.490	Δλ Nova Jan. 30.404	Stellar Occurrence
ScII	5031.03	$b^1D-z^1P^0$	4		−5.7	−4.8			
FeI.	5171.61	$a^3F-z^3F^0$	20	−4.15			−4.77	−4.40	3–8
NII.	5179.50	$3D^0-3^3F$	5			−4.66			5, 8
MgI	5183.62	$3^3P^0-4^3S$	125			−6.01			4, 5, 7, 8
TiII	5188.70	$b^2D-z^2D^0$	6			−5.37			4, 5, 7, 8
FeI .	5192.35	$z^7P^0-e^7D$	30			−5.47			4, 5, 7
FeII	5197.58	$a^4G-z^4F^0$	4	−5.99	−5.16	−5.92		−8.00	3–5, 7, 8
SII .	5201.00	$4^2D-4^2D^0$	2		−6.17	−5.65		−5.47	4, 8
SII	5201.35	$4^2D-4^2D^0$	2						
YII...	5205.73	$a^3F-z^3F^0$	80			−5.98			4, 5, 8
TiII	5211.54	$b^2F-y^2F^0$	0					−5.73	
TiII	5226.55	$b^2D-z^2D^0$	5			−4.96			3, 5, 6
FeI..	5226.87	$z^7P^0-e^7D$	15			−5.28			3, 5, 6
FeI. .	5266.56	$z^7P^0-e^7D$	30	−4.98		bl.			3, 4, 8
FeI. .	5269.55	$a^5F-z^5D^0$	60	−4.50		bl.			2, 4–8
FeI....	5273.17	$z^5D^0-e^5D$	3			−5.73			3, 4, 6–8
FeII .	5276.00	$a^4G-z^4F^0$	6	−5.73	−6.10	−6.06	−7.20	−6.40	3–8
CrII	5279.88	$b^4F-z^4F^0$	p			−5.74			4, 7, 8
FeI...	5283.62	$z^5D^0-e^5D$	18			−5.78			4, 6–8
FeII	5316.62	$a^4G-z^4F^0$	8	−5.47	−5.70	−5.94		−7.30	3–8
SII .	5320.70	$4^2D-4^2F^0$	7		−4.80	−5.95			3
YII...	5320.83	$a^3F-z^3F^0$	4			−4.06			
FeI...	5324.18	$z^5D^0-e^5D$	30			−4.50			4
OI.. .	5329.59	$3^5P-5^5D^0$	7		−5.09	−5.53			3, 5, 7, 8
OI.. .	5330.66	$3^5P-5^5D^0$	10			−4.93			3, 5, 7, 8
TiII	5336.80	$b^2D-z^2F^0$	4			−5.62			
FeI.	5339.93	$z^5D^0-e^5D$	12			−4.50			3, 4, 6–8
FeII	5346.54	$a^4G-z^4F^0$	p	−6.02		−7.10			7
FeI ..	5349.75	$z^3G^0-e^3G$	3	−6.01		−6.19			
ScII	5357.20	$a^3P-z^1P^0$	2			−6.85			
FeII	5362.87	$a^4G-z^4D^0$	p	−5.98	−5.60	−5.92			3–8
FeI..	5404.15	z^5G^0-39	30		−6.90				3, 4, 7, 8
CrII	5407.62	$a^4P-z^4P^0$	1		−4.42	−6.14			4, 8
FeI..	5410.92	z^5G^0-51	15			−5.61			4, 7, 8
FeI.	5429.71	$a^5F-z^5D^0$	40	−5.30					4, 7, 8
YII....	5497.42	$a^3P-y^3P^0$	50		−5.82				
ScII	5526.82	$a^1G-z^1F^0$	75	−6.55	−5.90	−6.00			
FeII .	5534.84	$b^2H-z^4F^0$	—		−5.84	−5.84			4, 5, 7, 8
FeI.. .	5572.85	$z^5F^0-e^5D$	30			−7.30			3, 4, 7
FeI....	5576.10	$z^5F^0-e^5D$	10			−6.71			
ScII ...	5640.99	$a^3P-z^3P^0$	15		−6.00				1–3, 7, 8
ScII	5657.89	$a^3P-z^3P^0$	25	−6.05		−6.39			7, 8
ScII..	5658.35	$a^3P-z^3P^0$	8						

TABLE 2 (*continued*)

El.	Laboratory λ	Multiplet	i	Δλ Nova Jan 5.492	Jan 18.476	Jan 23.547	Jan. 28.490	Jan. 30.464	Stellar Occurrence
YII ..	5662.94	$a^1G-z^1F^0$	200	−5.81	−6.14	−5.91			
SII ..	5664.73	$3^4F-4^4D^0$	3			−5.20			3
ScII	5667.16	$a^3P-z^3P^0$	10	−5.84					
ScII	5669.05	$a^3P-z^3P^0$	12			−5.53			3
ScII ..	5684.20	$a^3P-z^3P^0$	15			−6.60			
FeI ...	5701.56	$b^3F-y^3D^0$	7			−6.20			
FeI.	5708.11	z^3G^0-39	1			−4.90			
AlIII ..	5722.65	$4^2S-4^2P^0$	6	−4.65					1
SiI. ..	5867.50	$4^3P^0-4^3P$	1	−6.61		−5.69		−6.54	
HeI ..	5875.62	$2^3P^0-3^3D$	10				−6.68		1–8
FeI....	5914.12	$y^5F^0-3^5G$	8	−6.57					4, 7
NII .	5927.82	$3^3P-3^3D^0$	4	−5.82					
NII ...	5931.79	$3^3P-3^3D^0$	7	−5.10					
NII ..	5941.67	$3^3P-3^3D^0$	8	−5.17					
FeI....	6024.07	y^5F^0-39	15			−6.28			2, 3, 6, 7
FeI ...	6027.06	unclass.	4			−5.89			
NII ..	6170.16	$3^3F^0-4^3D$	1	−5.41					
ScII .	6245.63	$a^3P-z^3D^0$	20	−6.38					
NeI..	6334.43	$3s-3p$	34			−6.59			3, 6, 8
NII. .	6340.67	$3^3D^0-4^3P$	4			−5.40			
FeII .	6432.69	$a^6S-z^6D^0$	p	−7.75		−5.17			8
OI	6453.69	$3^5P-5^5S^0$	6			−5.49			5
OI	6454.55	$3^5P-5^5S^0$	7			−6.35			5
ScII ..	6604.61	$b^1D-z^1D^0$	10	−6.38					

Remarks to table 2

5031: This line is immediately to the red of the emission line λ 5018.45 of FeII and its measurement is difficult. It was measured also on January 31 with Δλ = − 5.3. There is a line of unknown origin at λ 5030.28 found in star 6. The line of SII at λ 5032.42, occurring in star 3, may have also contributed to the line in the nova.

5179: There is also a line of unknown origin at λ 5180.81 in star 4 and at λ 5180.90 in star 8.

5183: Also present on Jan. 31.446, Δλ = −5.93.

5192: FeI λ 5191.47 is probably present. There is a line on the plate of Jan. 31.446 which gives Δλ = −4.49 if identified with λ 5192.35

5201: Another possibility is SiII λ 5202.51, but the displacement of the nova lines would be somewhat too large.

5205: There is also a strong CrI line at λ 5206.04.

5226: The strong FeI line at λ 5227.19 may also be present.

5266: On the plate of January 30 there is a strong absorption band extending from λ 5248.9 to λ 5264.9 with the maximum of intensity at λ 5262.2. The shorter wave-lengths of this band are probably due to FeII λ 5256.9, occurring in stars 4, 7 and 8.

5269: The strong FeI line at λ 5270.39 is probably also present.

5273: The FeI line at λ 5273.37 is probably also present.
5279: AlII λ 5278.62 may also be present.
5283: AlII λ 5283.77 may also be present.
5357: This is a very faint ScII line and the identification is somewhat doubtful. Perhaps the lines of unknown origin at λ 5355.14 and λ 5355.27 found in stars 5, 6 and 8 also contribute to the formation of the nova line.
5640: Other possibilities: CII λ 5640.50, SII λ 5640.32, SII λ 5639.96, SiII λ 5639.49.
5669: SiII λ 5669.59 may also be present.
5867: SiII λ 5868.40 is probably present.
6340: There is also a faint emission band centered around λ 6341.

Table 2 gives the lines which may be reasonably ascribed to various elements. The table needs little explanation. Intensities of the laboratory lines of course hold good only for the lines in the same multiplet. The intensity of predicted lines is denoted with "p." Only five spectrograms, yielding the largest number of lines, are mentioned in the table, but reference to others will be found in the text. In the last column stars observed by Marshall are mentioned. It is natural that many of the stellar lines reported by Marshall cannot be expected in the spectrum of the nova on account of the presence of the emission bands.

The difference between the wave-lengths of the lines observed in the nova and in the laboratory is given for each date separately in columns 5 to 9. If two close laboratory lines are compared with the same absorption nova line, their wave-lengths are joined with a bracket. Wave-lengths in the spectrum of the nova given in this paper have been corrected for the orbital motion of the earth.

Presence of Various Elements

Ionized Scandium.—I.P. 12.80 volts. The presence of ScII during the first part of January is certain in spite of the fact that some stronger absorption lines do not appear in the nova. Of these λ 6300.70 and λ 6309.90 may be obliterated by the strong emission band of [OI]. It is significant that ScII is represented in A and B type stars by λ 5657 and λ 5669 only whereas the strongest laboratory line λ 5526 is absent.

In the nova only λ 5526 was accompanied by a faint emission.

Ionized Nitrogen.—I.P. 29.50 volts. The only lines of NII in the nova are those of the multiplets $3^3P-3^3D^0$, 3^3F^0

-4^3D and $3^5D^0-3^5F$. They were measured on January 5 and 23. The strongest line λ 5679 is apparently missing. However, NII shows an erratic behavior in the A and B type stars also. Thus in the multiplet $3^3P^0-3^3D$ the only two lines present are λ 5679 and λ 5676. The lines stronger in the laboratory than λ 5676 are absent. The same is generally true of other multiplets.

Ionized Sulphur.—I.P. 23.3 volts. Even though there are only four lines in the spectrum of the nova which may be safely ascribed to SII its presence is almost beyond doubt. Several more lines are in a bad position for measurement being concealed by stronger absorption and emission lines. Among these are λλ 5009, 5014, 5032, 5428, 6305 which lines account for practically all missing SII lines.

Ionized Chromium.—I.P. 16.6 volts. The strongest lines of CrII lie in the violet and ultra-violet region. Many of them have been identified in the nova spectrum by Grotrian and Rambauschke [1] and by Meyermann and Wellmann.[2] Only two lines in table 2 are ascribed to CrII, but on the plate of January 11 a line was measured at λ 5307.42 which may be the CrII line at λ 5313.59, giving $\Delta\lambda = -6.17$. The CrII lines at λ 5305, λ 5308 and λ 5310 were probably also present as explained in the notes to table 3. The lines CrII at λ 5337 and λ 5346 may also be present. They have been ascribed to TiII and FeII respectively. On January 23 an emission band of 7.6 A was measured. Its center is at λ 5420.3. It is undoubtedly CrII λ 5420.93.

Ionized Yttrium.—I.P. 12.3 volts. The lines of YII in the nova were faint. In addition to those mentioned in table 2 the lines at λ 5521 may also be present (see remarks to table 3). The line at λ 5662 was ascribed to YII but perhaps it should be identified with CII. Meyermann and Wellmann report only a few lines of YII.

Ionized Iron.—I.P. 16.5 volts. The lines of FeII were treated in full detail in my previous contribution. Here are included a few lines which were not accompanied by strong emission and identification of which is not certain.

[1] *Z. fur Astrophysik*, **10**, 209, 1935.
[2] *Z. fur Astrophysik*, **11**, 76, 1936.

Ionized Titanium.—I.P. 13.6 volts. There are very few TiII lines in the region under consideration. The strongest lines are all present in the nova. TiII was abundantly represented in the violet and ultra-violet region of the spectrum.

Singly and Doubly Ionized Aluminum.—I.P. 18.75 volts and 28.33 volts. There is some evidence for the presence of AlII and AlIII in the nova, but their identification cannot be certain.

Ionized Silicon.—I.P. 16.27 volts. The strongest lines of SiII λ 6371 and λ 6347 would be found at about λ 6365 and λ 6341, that is in the region of λ 6363 of [OI]. They were undoubtedly present at least on early plates before the [OI] lines became strong. See also remarks on the unidentified lines of table 3.

Neutral Iron.—This element is represented in the spectrum of the nova by numerous lines of high excitation potentials. Many more faint lines among those unidentified might also be ascribed to FeI.

Neutral Oxygen.—There were several lines of OI in the spectrum of the nova, especially in the earlier part of the observing period.

Neutral Magnesium.—Only the strongest line of MgI was found in the nova, but there are few strong lines in the visual region.

Neutral Neon.—Only one line in the spectrum of the nova can be attributed to NeI. Its presence is doubtful. The comparison spectrum of neon used for the nova spectrograms would permit an easy identification of neon in the spectrum of the star. Very little correspondence is found even allowing for the fact that some of the neon absorption lines may be concealed by emission bands.

Unidentified Absorption Lines

Table 3 gives a list of lines which could not be identified although in some cases a variety of choices was available. It would be easy to find some lines of neutral iron within a

TABLE 3
UNIDENTIFIED ABSORPTION LINES

Jan 5.492		Jan 18.470		Jan 23.547		Jan 28.490		Jan 30.464	
λ	i	λ	i	λ	i	λ	i	λ	i
								5019.5	1
						5171.1	1	5171.1	1
		5214.15	3	5214.72	3			5215.44	3
5282.30	1			5282.73	1				
5289.20	1			5291.1					
				5303.0	15				
				5305.8					
5348.82	1								
				5509.6	1				
				5516.1					
		5578.4	1						
				5572.07	1				
				5587.05	2				
								5595.29	1
								5698.9	1
								5704.3	1
				5709.7	1			5710.4	1
				5714.3	1				
								5861.06	1
								5866.59	1
5875.01	1								
						5893.0	1		
5931.84	1								
				6024.19	1				
6074.83	1								
6082.24	2								
6091.29	1								
6127.11	1								
6130.87	1								
6135.45	2			6134.7					
				6139.38	15	6138.7	2		
				6142.6					
6245.34	1					6236.1	1		
6249.01	1								
6254.47	1								
6257.13	1								
		6277.6	1			6278.2	1	6278.19	1
				6323.9	3				
		6327.7		6327.74	7	6327.2	1		
6329.0			3	6329.99	5				
	5	6335.4		6332.9	3				
6341.2									
				6349.5					
					8	6352.3	2		
6354.4	3	6354.6	3	6355.5					
6365.9									

TABLE 3 *(continued)*

Jan 5.492		Jan 18.470		Jan. 23.547		Jan. 28.490		Jan 30.464	
λ	*i*	λ	*i*	λ	*i*	λ	*i*	λ	*i*
6371.2	1	6370.2	2						
		6373.6	1						
				6421.55	½				
				6423.77	½				
				6430.76	½				
		6433.2	1	6433.8 }		6434.1	1		
					10	6438.2	1		
				6443.3 }					
				6445.98	½				
				6453.45	½				
				6457.70	1				
				6461.00	1				
		6464.2	2	6464.00	2				
		6467.3	3	6466.00	1				
				6473.40	1				
				6489.33	1				
				6493.21	½				
				6498.21	1				
				6504.23	½				

Remarks to table 3

4924: A faint line at λ 4924.77 was measured on the spectrogram of January 31. It may be identical with the line of unknown origin at λ 4932 found in stars 7 and 8.

5019: This line was measured also on the spectrogram of January 31 at λ 5019.88. It is inside the broad emission line FeII λ 5018.45 and is perhaps connected with the FeII system. There are no lines in Marshall's stars which would correspond to the nova line. The FeI line λ 5022.24, occurring in stars 3, 4, 5, 7, and 8 would make the displacement too small.

5171: This is a faint line in the emission line of FeII λ 5169.05. Perhaps it is identical with the unidentified line at λ 5177 observed in stars 4, 5, 6, 7 and 8.

5214: The normal wave-length of this line should be in the neighborhood of λ 5219.8. It is impossible to suggest any consistent identification. It is certainly not Cu λ 5220.09 because a much stronger Cu line at λ 5218.21 (i 10 : 6) belonging to the same multiplet is absent. This line may belong to PrII which has the same wave-length as the Cu line λ 5220.09. TiI has a line at λ 5219.71 but other much stronger lines of TiI are absent in the nova. Dunham reports a line in α Persei at λ 5220.37 which belongs to NiI, but this identification in our case is doubtful on account of the absence of other lines of NiI in the spectrum of the nova. There are no lines at λ 5220 in the spectra of A and B type stars, the nearest lines being λλ 5215 and 5226. In the nova this absorption line is about 4 A wide. It is of considerable intensity (i 3) and is probably a blend of two or more lines. It is next to a strong line (i 5) at λ 5221.59 which is 4.7 A wide. This latter line is probably a blend of TiII and FeI, as suggested in table 2. The line at λ 5214 cannot be seen on the spectrograms before January 18 and after January 30.

5282: This is a faint but well defined line probably corresponding to the line at λ 5288 which occurs in stars 4, 5, 7 and 8. The identification of this line with

YII λ 5289.82 is unlikely. It would give $\Delta\lambda = -7.30$ and -7.32 for the two dates, making it considerably greater than for the general run of lines. Also the YII line λ 5205.73, though present in the spectrum of the nova, is quite faint, and in the laboratory sources this line is sixteen times as strong as λ 5289.

5289. This line was measured only on January 5. It corresponds probably to the unidentified line λ 5295.45, thus giving $\Delta\lambda = -6.25$, which occurs only in α Andromedæ.

5305: This is one of the strongest absorption bands in the whole spectrum of the nova. It stretches for 14.7 A from λ 5291.1 to λ 5305.8. The strongest part of the band at λ 5303.0 corresponds probably to CrII λ 5308.43 which occurs in stars 7 and 8. This band is undoubtedly a blend of several absorption lines, which may include in addition to the above-mentioned line OI λ 5299.00, FeI λ 5302.30, CrII λ 5305.87 and CrII λ 5310.69. All these lines occur in Marshall's stars. On January 11 and January 12 well defined absorption lines were measured at λ 5307.42 and λ 5306.47 corresponding probably to the CrII line at λ 5310.69. The three CrII lines mentioned here were measured by Beer[1] in emission on the plate of January 4.

5348: This line was measured only on January 5. It may be identical with the unidentified line at λ 5355 occurring in stars 5, 6 and 8.

5509: This is a faint absorption band 6.5 A wide, probably a blend. Lines at λ 5516.2 have been measured in stars 3 and 4, and at λ 5519.1 in stars 4 and 5. Their origin is uncertain. There are two strong TiI lines at λ 5514.3 and 5514.5 and also a strong MnI line at λ 5517.8. The longer wave-length of this band may be due to YII λ 5521.59.

5572: A faint line of uncertain origin. A line at λ 5578 occurs in stars 6, 7 and 8.

5578: This faint line may be identical with the line at λ 5583 observed in stars 6 and 8.

5587: A rather strong line.

5595: A faint line of uncertain origin.

5698: This may be the enhanced solar line at λ 5705.12 of uncertain origin.

5704: This line perhaps corresponds to the unidentified line at λ 5710 found in star 3.

5709: The normal wave-length of this line should be about 5715. There is nothing in Marshall's stars between λ 5710 and λ 5722. This is probably not the NiI line at λ 5715.10 because other strong NiI lines, notably at λ 5476.92, are not present in the spectrum of the nova.

5714. This line may be identical with the unidentified enhanced solar line at λ 5719.6. The identification of the nova line with AlIII 5722.65 is unlikely, since it would give $\Delta\lambda = -8.4$.

5852: A sharp line at λ 5852.7 was measured on February 24. Perhaps this is FeI λ 5859.6.

5861: This is perhaps the line λ 5865 occurring in star 3.

5866: This is probably the line λ 5871 measured in stars 4, 5, 6 and 8.

5875: A faint line which may belong to the D-system. Also on January 11 two lines were measured in this region, λ 5877.00 and λ 5880.29.

5893: A very faint line of uncertain origin in the D-system emission.

6024: The normal wave-length should be about 6030. There is nothing in Marshall's stars or in α Persei which might be identified with this line. Perhaps this is the NeI line λ 6030.00, which would give $\Delta\lambda = -5.81$, a value quite acceptable.

5936: A faint line. There are no lines in Marshall's stars between λ 5916 and λ 5948.

6074: This line is probably identical with λ 6083 occurring in stars 6 and 8.

6082: Probably is not CrII λ 6089.80 measured in star 7.

6091: Probably is not CrII λ 6098.62 occurring in stars 1 and 2.

[1] *Monthly Not. R. A. S.*, **95**, 538, 1935.

6139: This is one of the strongest absorption bands in the spectrum of the nova. On January 23 it is 7.9 A wide, gradually fading out. The strongest portion is at λ 6139.38. The band is probably composite. The strongest part corresponds probably to the enhanced solar line at λ 6144.99, giving $\Delta\lambda = -5.61$. The flanks may be due to BaII λ 6141.73, NeI λ 6143 1, and FeII λ 6147.75 There is emission to the red of this absorption band extending as far as λ 6180. There are several lines in this region in the spectra of Marshall's stars. On January 28 only the solar line is present. On January 5 distinct lines were measured in this neighborhood. Of these λ 6127 is extremely faint. It may correspond to a line at λ 6131.38 occurring in star 6.

6236: A faint line of uncertain origin. On February 7, a line at λ 6230.19 was measured.

6245 to 6257: There are no absorption lines in Marshall's stars between λ 6247 and λ 6271.

6278: A faint sharp line, also measured on February 6 λ 6378.11 and on February 7 λ 6378.03. It is probably the unidentified line at λ 6285 occurring in stars 5, 6 and 8.

6323 to 6341: This band was prominent in January but disappeared entirely in February. On the plate of January 23 it extends from λ 6323.9 to λ 6332.9 evidently consisting of a number of absorption lines of unequal intensity. The sharp line within the band at λ 6329.99 is probably NeI 6334.43, giving $\Delta\lambda = -4.44$, while the line at $\Delta\lambda = 6327.74$ is perhaps identical with the lines of unknown origin at λ 6332.74 and λ 6332.49 measured in stars 2 and 5. There are also several FeI lines in this region. The edges of the band may perhaps be considered as absorption lines. On January 31 a line at λ 6321.74 was measured. It is probably the unidentified line at λ 6327 found in stars 3 and 8. On January 5 this is the strongest absorption band in the region extending from λ 6329 to λ 6341. Undoubtedly SiII λ 6347 contributes to the red wing of this band. The SiII line is present in stars 2, 3, 4, 5, 6 and 8. On February 24 a sharp absorption line was measured at λ 6335 with indefinite absorption to the violet.

6349 to 6355: On the spectrogram of January 23 this is a strong band of 6.0 A width. There are only faint FeI lines that might be expected in this region. The line at λ 6356.43 measured in star 6 may be present in this band. This band is immediately to the violet of the strong emission line of [OI] λ 6363, but is probably not connected with it in any way. The absorption line was not noticeable most of the time, and the OI emission line at λ 6300 certainly had no absorption line to the violet.

6354 to 6365: On January 5 this is a wide band (9.5 A width) of a considerable intensity. On January 18 only a narrow line at λ 6354.6 could be measured. There is nothing in Marshall's stars at this place. The SiII line λ 6371 undoubtedly contributes to the red wing of this absorption band. The SiII line is present in stars 2, 3, 4, 5, 6 and 8.

6371: A faint line of uncertain origin. There is nothing in Marshall's stars which might be identified with this line.

6421, 6423, 6430: Three very faint lines of uncertain origin absent in the spectra of Marshall's stars.

6433: A very strong absorption band of 9.5 A width, probably of a complex structure. Perhaps the main contributing absorption lines are CaI λ 6439.09 and λ 6449.79. There is nothing in the spectra of Marshall's stars to correspond to these wave-lengths.

6453 to 6504: Eleven faint absorption lines whose identification has not been possible. They are certainly not atmospheric lines even though some wave-lengths coincide very closely. The strongest atmospheric lines in this region, however, are missing in the spectrum of the nova. The nova lines probably correspond to at least some lines measured by Marshall, but not identified. Thus λ 6457 is probably the same as stellar λ 6464 (stars 3, 5, 8), λ 6461 corresponds to λ 6467 (stars 3, 5, 6), λ 6464 to λ 6470 (stars 5, 6, 8), λ 6466 to λ 6473 (stars 3, 5), λ 6489 to λ 6497 (stars 3, 5), λ 6498 to λ 6503 (stars 5, 6) and λ 6504 to λ 6512 (stars 3, 5, 6, 8). It will be noted that all these lines occur in Vega (star 5).

6502: A rather strong absorption line was measured on the spectrogram of January 11 at λ 6502.17. It may be connected with the FeII systemt a λ 6516.09. It may also be the NeI line at λ 6506.53.

convenient distance from the nova lines but this would hardly be identification. Perhaps some of the lines in table 3 are really iron lines but I considered it safer to give them as they were measured. There is no material for comparison of these measures with the lines found in previous novæ as the visual parts of the spectra of the novæ is not well known.

Intensities of the lines given in table 3 are visual estimates and are comparable only within a small range in the spectrum. Intensities of 1 correspond to the faintest lines the presence of which was considered certain. Intensities of ½ refer to doubtful lines.

General Remarks on the Absorption Spectrum

The absorption spectrum of hydrogen, sodium and ionized iron was discussed in detail in my first paper. Thirty-one absorption lines were mentioned there counting the different components of the same line only once. Fifty-seven lines of elements other than those mentioned above have been identified in table 2 of this paper. It is impossible to say exactly how many unidentified lines there are in table 3 since some of the lines measured are undoubtedly blends. The best count gives some sixty-two lines, but some of them may be different components of the same lines. We have thus about 150 absorption lines in the spectrum of the nova between Hα and Hβ measured principally on the spectrograms taken in January. Comparing the spectrum of the nova with the stars studied by Marshall we have the following table:

TABLE 4

NUMBER OF LINES IN COMMON IN THE NOVA AND THE STARS

Star	1	2	3	4	5	6	7	8
H, Na, FeII.	2	3	13	15	10	11	16	21
Table 2 . .	3	4	21	24	19	13	26	26
Table 3	1	5	11	12	16	14	8	19
Total	6	12	45	51	45	38	50	66
Percentage. .	4	8	30	34	30	25	33	44

It is seen from table 4 that the best correspondence is between the spectrum of the nova and that of star 8, which is α Cygni. Even in this case only 44 per cent of the absorption lines in the spectrum of the nova can be found in the spectrum of α Cygni. On the other hand Marshall lists in the spectrum of this star between $H\alpha$ and $H\beta$ 193 lines of which 65, that is only 35 per cent, correspond to those in the nova. Undoubtedly the emisson bands of the nova obliterate many fainter absorption lines and thereby render the resulting spectrum more different from that of α Cygni than it really is. Some of the lines in the nova may be components of the α Cygni lines displaced farther to the violet than those identified. Indeed this is true of the ionized iron lines where there were at least two absorption components but the identification in this case was made easy by the presence of emission bands. Marshall's spectrograms were obtained on the films giving better definition throughout the spectrum than the plates of the nova. Therefore the absorption spectrum of the nova in the visual region was probably more similar to that of α Cygni than it may appear from table 4.

The chief difference between the absorption spectrum of α Cygni and that of the nova seems to be the presence in the nova of YII and ScII, although some of the ScII lines are present in α Cygni. Lines of both of these elements were identified in the visual spectrum of the nova by Merrill so that there is no doubt as to their presence.

The general absence of the helium line D_3 in the spectrum of the nova is remarkable. It was found on only one plate,

that of January 28. It is very strong in all the stars investigated by Marshall.

The rest of the stars show somewhat less similarity to the absorptions spectrum of the nova, except γ Orionis and β Tauri which have practically nothing in common with the nova. It may be said that in January 1935 the spectrum of the nova was definitely of A-type with considerable resemblance to the spectrum of α Cygni. The B-type stage had not been reached in January. In February practically all absorption lines except those of FeII, Na and H disappeared, but the spectrum of the nova still bore little resemblance to that of a B-type star. However, this point can be settled only after a study of the photographic region of the spectrum.[1]

Remarks on Emission Spectrum

In a spectrum as complicated as that of a nova considerable freedom is left to the investigator for the interpretation of the observational material. Especially difficult are measures of broad emission bands of the spectrum where the personal equation seems to be great.

The displacements of the centers of emission bands are usually considered as representing the velocity of the nebulous envelope of the nova as a whole. Since the emission bands are seldom sharply defined and their width is affected by instrumental and observational conditions the results of individual investigators are often discordant. Thus the displacement[2] of the centers of emission bands in the spectrum of Nova Aquilæ 1918 as found by different observers varied from -13 km. sec. to -120 km. sec. In Nova Persei 1901 the corresponding figures were from $+6$ km. sec. to $+140$ km. sec.

In comparing the results of individual observers it should be remembered that the displacement of the emission and absorption features in the spectrum of a nova is unquestion-

[1] D. B. McLaughlin, *Pop. Astr.*, **43**, 265 and 323, 1925, found that the spectrum of the nova was of the α Cygni type until December 21, 1934, after which date it changed into a spectrum of the ϵ Aurigæ type (cF5).

[2] Vorontsov-Velyaminov, *New Stars and Galactic Nebulæ*, 1935, p. 228 ff.

ably a function of time. Only after a considerable lapse of time following the outburst do various emission bands give consistent results. Abundant material proving this point may be found in many investigations on the previous novæ. Thus W. H. Wright[1] in his study of Nova Geminorum, 1912, found on the plate of March 20, 1912, that the displacements were + 0.8 A, + 0.6 A, + 1.6 A, + 2.4 A and + 4 A for the hydrogen lines ζ, δ, γ, β and α. The displacements of the nebulium lines N_1 and N_2 were − 1.9 A on May 5, and − 2.3 A on May 12. Adams and Burwell[2] obtained in the spectrum of Nova Ophiuchi, 1919, displacements for the centers of emission lines ranging from + 0.5 A to + 1.7 A. It is significant that the largest and the smallest displacements obtained for the same element FeII. For the lines λ 4522 and λ 4583 of the multiplet $b^4F - z^4D^0$ of FeII the displacements of the centers were + 1.4 A and + 1.9 A corresponding to the velocities + 93 km./sec. and 124 km./sec. H. Spencer Jones[3] found in the spectrum of Nova Pictoris, 1925, on June 17, from the lines λ 4924 and λ 5018 of the multiplet $a^6S - z^6P^0$ of FeII the radial velocities − 9.7 and + 17.5 km./sec. On June 25 the multiplet $b^4P - z^4D^0$ gave for the lines λ 4303 and λ 4273 the velocities − 3.5 and + 30.2 km./sec.

It is evident from these examples that the lines even in the same multiplet of an element do not necessarily give the same radial velocity. Furthermore, radial velocities derived from the same lines change rapidy and by large amounts. A different combination of individual measures may result in a considerably different mean value of the radial velocities. But if the spectrograms cover approximately the same period of time and are distributed approximately in the same way throughout this period it is of some importance to compare results of different observers in order to see how much in the reported spectral features should be considered as real, and

[1] *Lick Obs. Publ.*, **14**, part 2, tables 7 and 16.

[2] *Ap. J.*, **51**. 121, 1920.

[3] *Annals of Cape Observatory*, **10**, part 9, pp 294 and 324.

how much should be ascribed to the inherent uncertainties in measuring diffuse formations.

Dr. P. W. Merrill of the Mount Wilson Observatory has published a paper [1] based on material similar to that used by me. His results for the emission features of [OI] and FeII may be compared with mine. Our values for the displacement of absorption lines are generally in good agreement and there is no especial need for their discussion.

First one is struck by the sizes of the probably errors in the determinations of the displacement of emission centers. For the [OI] line λ 6300, for instance, my value is 20.6 ± 6.6 against Merrill's 21.0 ± 0.4. Most of this difference is due to the fact that I have probable errors of a single observation instead of the mean. My results should read 20.6 ± 1.3 km./sec. for λ 6300 and 22.3 ± 2.9 km./sec. for λ 6363. However, in this case the size of the probable error does not characterize the consistency of measurement. It is clear both from my diagram (Fig. 1, *op. cit.*) and from Merrill's diagram (his fig. 3) that the centers of emission lines underwent frequent displacements from the mean. The character of these displacements is approximately the same on both diagrams, but the amplitude of oscillation derived by me is considerably greater. This latter circumstance is probably due to the difference in the method of measurement. Whereas I always took the outer edges of the emission bands, Merrill took the average of many measures of the edges, of emission maxima of the flanks, of the estimated middle of the bands, etc. presumably reducing thereby the scattering of results.

We may note that Merrill's curves of the separation of the emission components of [OI] and of the width of the bands do not run parallel to each other but diverge toward the end of the observing period. This means that the components not only were increasing in width but also that their centers were moving from the center of the emission band, which fact is entirely in accord with my results.

When we come to the displacement of the centers of emis-

[1] *Ap. J.*, 82, 413, 1935.

sion bands we notice some discordance in the results obtained.

In the case of the [OI] lines Merrill finds the mean velocity of -21.5 km. sec. whereas my value is -21.2 km. sec. This excellent agreement is, however, mostly due to chance. Dr. Merrill adopted for the wave-length of one of the lines the value 6300.32 A based on the new measurement by Harang and Vegard [1] whereas I used Hopfield's value of 6300.23 A. It is difficult to say which figure is more nearly correct. The larger figure was obtained during an auroral display and may conceivably be affected by the line of sight motion of the auroral streamers. Assuming that 6300.32 is correct I obtain from my measures $v = -24.7$ against Merrill's -21.0. However, the mean for the three [OI] lines [2] comes out to be -21.4 km./sec. which is again almost identical with Merrill's mean value -21.5 km./sec.

For the emission FeII lines Merrill obtains a general velocity of approach equal to 7.3 km./sec. whereas my measurement indicates a velocity of recession of the order of 22 km. sec. This discrepancy is not very serious in view of the diffuseness of some FeII lines. Moreover, Merrill left out the strongest multiplet $a^6S-z^6P^0$ for the λ 5169 of which he obtained a large positive velocity, amounting on December 30 and 31 to as much as 94 km./sec. This is precisely the multiplet that gives the largest velocities of recession throughout the whole period of observation covered by my spectrograms. He also did not consider the line λ 5316 which gave again a positive velocity. Taking only the multiplets $a^4G-z^4F^0$ and $b^4D-z^4P^0$ (without λ 5316) the average velocity I obtain from my measurements is $+5.2$ km./sec. against Merrill's -4.9 km./sec. The discrepancy is therefore much reduced and can wholly be accounted for by observational difficulties. It is interesting to note that my results of the erratic behavior of the multiplet $a^6S-z^6P^0$ and of λ 5316 as contrasted with the rest of the FeII lines in

[1] *Nature*, 135, 542, 1935.

[2] Neglecting two poor measures of the green line as explained in my first paper, page 9.

the visual region seem to be in agreement with Merrill's measures.

It is of course somewhat of a contradiction in terms to determine the average velocity of a certain element by arbitrarily suppressing the lines which give discordant results. Perhaps all lines of the same element should not give the same velocity. Some correlation between the velocities shown by different lines and excitation or ionization potentials is to be expected, but this task cannot be undertaken until the spectrum of the nova is studied in the photographic region.[1]

It is seen from the foregoing analysis that so far as emission features of [OI] and FeII Merrill and the writer are in substantial agreement. It is to be regretted that Merrill did not measure the more difficult emission bands of hydrogen and sodium where a check on my results might be desirable.

It is generally conceded that emission lines of the same multiplet of the same element may have in the spectrum of a nova a substantially different structure. Some examples of such behavior were given in my first paper. The most remarkable circumstance is the difference in the behavior of the [OI] lines λ 6300 and λ 6363. These lines have one metastable level in common and should behave exactly alike. It is seen from table 4 of my first communication that the widths of the red and violet components in these lines were sometimes different. Thus on January 31 the red component of λ 6363 was the wider, whereas in λ 6300 it was the reverse. It is true that the inner edges of the components were ill-defined and measurement was difficult, but since λ 6300 was always much the brighter of the two one would expect the components in λ 6300 to be always uniformly wider than in λ 6363. The displacement of the center of these two lines also differed sometimes by considerable amounts even though the mean result for the whole period of observation is substantially the same. The relative intensities of the components were often different. On March 2 for instance the

[1] Indeed such correlation is indicated in the Mount Wilson preliminary results, *Pub. A. S. P.*, 47, 205, 1935.

red component in λ 6363 was the stronger, while in λ 6300 the violet component was more intense. Occasional differences in the profiles of these two lines is confirmed also by microphotometer tracings.

On fig. 5 of my first contribution the profiles of λ 6363 and of 6300 on February 7 differ very appreciably. The visual estimates of the intensities of the red to the violet component are 12 : 10 for the first line and 10 : 10 for the second line. It may be argued that the absorption line to the violet of λ 6363 cut off the violet component of this line thus introducing an apparent difference in the aspect of λ 6363 and λ 6300. It is impossible to settle this point as on this date λ 6363 had no well defined components in contrast with λ 6300. However, the total width of λ 6363 on this date was 15.79 A whereas that of λ 6300 was only 15.19 A, and the displacements of the centers was − 0.45 A and − 0.24 A, respectively. It would seem that λ 6363, contrary to expectations, really spread farther to the violet of the center than λ 6300. Therefore the presence of an absorption line near the violet wing of λ 6363 cannot be considered as a satisfactory explanation of its behavior. The same considerations apply also the spectrograms of March 2.

Even though the novæ exhibit the most striking departures from the thermodynamic equilibrium one must be careful in drawing conclusions from the observed facts.

The difference in the behavior of λ 6363 and λ 6300 were not sufficiently great to be considered as proved beyond doubt. It is possible that absorption lines superimposed on these two [OI] lines may influence their shape and intensity although some of the data on this point came at the end of the observing period when the absorption lines practically disappeared from the spectrum.

The forbidden lines of OI were observed in many previous novæ but they never were prominent so that the direct comparison in this respect between Nova Herculis and other novæ is impossible. But the analogous lines of [OIII] are strong in most novæ at a later stage of their history and in

gaseous nebulæ. There is abundant material on the behavior of these lines.

The three lines of [OIII] are: λ 4363, $^1S_0-{}^1D_2$; λ 4959, $^1D_2-{}^3P_1$, usually denoted with N_2; and λ 5007, $^1D_2-{}^3P_2$, usually denoted with N_1. The first line, λ 4363, in the novæ often differs in behavior from the N_1 and N_2 lines. The relative intensities of N_1, N_2 to λ 4363 are widely different for different novæ.[1] In Nova Geminorum, 1912, Wright[2] found on several occasions that the relative intensity of the edges in λ 4363 and in $N_{1,2}$ were reversed. However, N_1, and N_2 behaved in exactly the same manner. Adams and Pease[3] reported that later in this nova N_1 disappeared but N_2 remained present. Wright[4] explains this observation by the presence of an unidentified line at λ 4940 which has nothing to do with N_2. Similarly Spencer Jones[5] measured a line in the neighborhood of N_2 in the spectrum of Nova Pictoris, 1925. N_1 was absent, but it was found impossible to attribute this line to [OIII].

The spectrum of Nova Aquilæ, 1918, was investigated by Moore and Shane[6] more than a year after the original outburst. The structure of the N_1 and N_2 lines, which stretched for some fifty angstroms each, is similar although a small difference can be seen. Thus the position of the analogous maxima in respect to the nuclear line and with respect to each other is not the same. But the difference is small and perhaps may be accounted for by the difficulties of measurement.

It is well known that in the spectra of gaseous nebulæ the N_1 and N_2 lines are often prominent. The monochromatic images of the planetary nebulæ envelopes in these two lines are of different size, N_1 being invariably the larger. It would seem that N_1 has its origin in a larger volume of space around the nucleus than N_2. However, here we have again

[1] Adams and Pease, *Ap. J.*, 40, 294, 1914.
[2] *Op. cit.*, table 21.
[3] *Proc. Nat. Acad. Sci.*, 1, 391, 1915.
[4] *Op. cit.*, 91.
[5] *Op. cit.*, p. 145.
[6] *Lick Obs. Bull.*, 10, 32, 1919.

Wright's dictum:[1] "From the appearance of the images I am inclined to think that with equal intensity N_2 would appear equal in size to N_1, and that the two disks are equal."

The new study of the spectra of planetary nebulæ by Berman[2] confirms in general Wright's opinion. The ratio of intensity of N_1 to N_2 seems to be the same for all investigated nebulæ. The contour diagrams of the lines of equal intensity in the monochromatic images of N_1 and N_2 do not differ sufficiently to warrant a conclusion that N_1 does not behave in the same way as N_2. It is interesting to note that the λ 4363 shows an entirely different behavior from nebula to nebula which is true also of the novæ.

The most striking result in the difference of the behavior of N_1 and N_2 in the spectrum of the Orion nebula was found by the Bergedorf observers.[3] The ratio of intensity of N_1 to N_2 was found to be a function of the place in the nebula at which the spectrum was obtained. The ratio changed from 2.5 to 4.0. However, a later revision of the observational data by Minkowski[4] considerably reduced this difference with the final conclusion that the ratio of intensity of N_1 and N_2 is the same within the errors of observation throughout the nebula.

It appears that so far as the nebulæ are concerned there is no conclusive evidence that N_1 and N_2 behave differently, and there is little more than a suspicion that in the novæ these two lines may not behave in the same way. The observation on the [OI] lines in Nova Herculis, if confirmed, is the first definite evidence that two forbidden lines coming from the common upper level might behave differently.

It might be of interest to note here that the structure of the [OI] bands in Nova Herculis with two strong components symmetrically situated in respect to the normal position of the line was observed in previous novæ, such as Nova Gemin-

[1] *Lick Obs. Publ.*, **13**, 200, 1918.
[2] *Lick Obs. Bull.*, **15**, 86, 1930.
[3] *Z. für Astrophysik*, **6**, 355, 1933.
[4] *Z. fur Astrophysik*, **10**, 202, 1935.

orum, 1912 [1] and Nova Aquilæ, 1918.[2] Even such details as the presence of the narrow undisplaced emission between the strong components was noticed before.

Among the more prominent of the fainter emission bands measured on our spectrograms and not discussed in the previous contribution the following may be mentioned:

TABLE 5

FAINT EMISSION BANDS

Jan. 30.464		Jan 31.416	N Aquilæ [3]	Identification
Center	Width			
λ 5686.1	14.2 A	——	5645–5706	5686.2 NII
5743.0	10.7	——	5745	5747.3 NII
5757.5	10.2	——	5759	5755.0 [NII]$^1D_2-^1S_0$
5764.9	12.5	——	——	5767.4 NII
5991.1	13.4	5991.65	——	5991.4 ⊙+

Of course many more emission bands might be included in table 4, but they were not definite enough to be measured. Among the bands in table 5 especially interesting is the presence of the forbidden line of NII commonly observed in the novæ. The other two lines of NII situated in the visual region, namely λ 6548.4, $^3P_1-^1D$, and λ 6583.9, $^3P_2-^1D$ were undoubtedly present but submerged in the extensive structure of Hα.

The lines at λλ 5686, 5743 and 5765 are ascribed to NII although the wave-lengths do not exactly correspond to the nitrogen lines. However, the bands were diffuse and difficult to measure. So far as λ 5686 is concerned it is possible that ScII λ 5684.2 is also present. According to Merrill this line was observed in emission late in December, 1934. The line λ 5526 of ScII was also accompanied by a faint emission. These lines were found also on spectrograms taken in February, but they are so diffuse that precise measurement is not possible.

[1] Wright, *Lick Obs. Bull.*, 14, part 2, p. 81.

[2] Moore and Shane, *op. cit.*

[3] G. F. Paddock, *Publ. Astr. Soc. Pac.*, 30, 244, 1918.

The line λ 5991 is included here mostly because in my first communication a misprint occurs on page 32 where the wave-length of the line observed by Beer is given as λ 5191.4 instead of λ 5991.4. Also a very faint absorption was later measured to the violet of this line on January 31, giving $\Delta\lambda = -8.33$, if the identification is correct.

Conclusion

A study of the complex spectrum of Nova Herculis in the visual region for only a limited period of time cannot reveal all the transformations undergone by the nova. A systematic study of all the abundant material gathered at various observatories is necessary for anyone who attempts to build a theory of the nova phenomena. Still some outstanding features observed in the visual spectrum of the nova both at Mount Wilson and at the Perkins Observatory are definite enough to be considered of permanent value. They should be taken into account in any theoretical study of the nova. Perhaps it should be mentioned here that all the displacements of spectral lines from their normal positions have been considered by me as a simple Doppler effect.

The first remarkable fact is the accelerated expansion of the envelopes in the first three months of 1935. The velocity given by one set of absorption lines of FeII and NaI increased according to Merrill from 320 km./sec. at the end of December to 400 km./sec. at the end of March. My figures are substantially the same. A similar but more complicated picture is revealed by other components of absorption lines, the width of emission bands, etc.

It is reasonable to suppose that the accelerated expansion of the envelopes is due to the pressure of light from the nucleus of the nova. The difficulty of this interpretation lies in the fact that the behavior of the lines of the same element was not the same. The curves showing the displacement of the components sometimes differ very greatly. Thus the behavior of various FeII multiplets as well as of Hα and Hβ was entirely different. In fact according to Merrill one of

the components of the sodium lines showed between December 24 and 26, 1934, a decrease in velocity from 190 km. sec. to 177 km. sec. while another component of the same lines changed its velocity in the same interval from 290 km. sec. to 320 km. sec. If the first set of components was originated in the outer shell, and the second set in the inner shell, then these two shells were affected by the action of the nucleus in exactly the opposite way. A similar difficulty is observed in various multiplets of FeII in which the changes in the displacement factors now run parallel now in opposite directions.

The idea of envelopes expanding with a uniform speed must be abandoned in the case of Nova Herculis.[1] From lack of reference in literature on novæ to the accelerated expansion of the envelopes one might conclude that this phenomenon was peculiar to Nova Herculis. However, in Nova Geminorum, 1912, Wright[2] found a considerable increase in velocity in what he calls absorption III. In the interval of time between March 20 and April 4 the displacement factor decreased first from 57 to 41 and then increased again to 70. The corresponding change in velocity was from 1700 km. sec. to 1200 km./sec. and then to 2100 km. sec. Absorption II on the other hand hardly changed at all during this period.

In the spectrum of Nova Pictoris, 1925, Spencer Jones found the increase in the displacement of absorption III between June 9 and June 27, 1925, to be from 100 km./sec. to 122 km./sec. Absorption II in the same interval showed an increase from 297 km. sec. to 331 km./sec. The curves showing the changes of velocity displacements[3] are very similar to those of Nova Herculis. Acceleration is rapid at the beginning but slows down as time goes on. There is even evidence of some periodic oscillation as in Nova Herculis. The final history of Nova Herculis, as is well known, was similar to that of Nova Pictoris: both of them split into two components.

[1] In *Publ. Am. Astr. Soc.*, 8, 227, 1936, F. L. Whipple and C. P. Gaposhkin assume the ejection of material from the core of the nova with constant velocity, which of course is not the same idea as involved in the hypothesis of envelopes expanding with constant velocity.

[2] *Lick Obs. Publ.*, 14, part 2, p. 77.

[3] *Op. cit.*, p. 172, fig. 5

It is evident that the accelerated expansion of envelopes was not a phenomenon peculiar to Nova Herculis. It is evidently rather a common trait among the novæ.

The early appearance of the forbidden lines of oxygen in Nova Herculis was also no exception. In Nova Geminorum for instance these lines were observed by Wright immediately after the maximum of light. However, the strength and the structure of the [OI] lines in Nova Herculis were remarkable. It would seem that the existence of two sharp maxima in these lines on each side of the center is a definite indication of the existence of two components in the star itself before the two components were observed visually. The difficulty in accepting this interpretation lies again in the difference of the behavior of various lines. It is true that such double structure was observed by Spencer Jones in Nova Pictoris [1] even though it was not so well pronounced as in Nova Herculis and was not common to all emission lines. On the other hand such maxima on the edges of emission bands were observed in Nova Geminorum and Nova Aquilæ which never showed any duplicity. Therefore the double features of the emission bands in Nova Herculis are evidently not connected with the existence of two stellar components but rather constitute a property common to all novæ. They might possibly be interpreted as indicating some emission along the arms of an ejection of gaseous matter in the nova.

Another fact probably common to all novæ but investigated in Nova Herculis in greater detail than any other nova is the large difference in the velocity shown by the centers of emission bands. This difference in velocity would eventually lead to a separation of elements and localization of emissions in different parts of the nova envelope. Such phenomena are observed in the planetary nebulæ which may be nothing but "old novæ."

PERKINS OBSERVATORY,
DELAWARE, OHIO,
April 3, 1936.

[1] *Op. cit*, p. 151.

PREHISTORIC MAN IN PALESTINE

GEORGE GRANT MacCURDY

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ABSTRACT

Palestine is at the meeting place of three great land masses, in one of which man first appeared. In spreading to the other two he might well have made use of the route by way of Palestine. Even as early as the Lower Pleistocene, man developed both physically and culturally to a point where such terms as *Eoanthropus* and *Sinanthropus* seem appropriate, and where the term *Homo* is not much too high and *Pithecanthropus* not much too low. These oldest forms were all found on the periphery of the Euro-Asiatic land mass. This geographic distribution from eastern Asia to western Europe tends to support the view now generally held that man originated somewhere in Asia—a view supported likewise by the results of recent researches which seem to prove that during the Pleistocene period there were no land bridges across the Mediterranean either at Gibraltar or at Sicily and Malta. The fossil mammals of Malta and Sicily have Asiatic or European rather than African affinities.

Recent discoveries of fossil mammals in the caves of Palestine and Syria indicate that during the early Pleistocene the connection of Asia with Africa was as pronounced as that between Asia and Europe. The mammals had a common source in Asia migrating north of the Mediterranean into Europe and south of the Mediterranean into Africa. As yet we have found very few skeletal remains of man dating back to the Lower Paleolithic period, although his cultural remains have been found at many sites. When we come to the Middle Paleolithic, generally referred to as the Mousterian epoch, we are now fairly well documented as to both physical and cultural types especially the latter. The author of Mousterian culture is the race known as *Homo neandertalensis*.

Skeletal remains of Neandertal man have been found not only on the north shore of the Mediterranean at Gibraltar and Saccopastore near Rome, but also further inland at about a dozen sites from France and Belgium in the west through Germany and Yugoslavia to the Crimea in the east. To date no skeleton of Neandertal man has been found on or near the southern shore of the Mediterranean. The eastern shore has only begun to reveal its story and what a rich story it is turning out to be.

In 1925 Turville-Petre, for the British School of Archæology in Jerusalem, found in the Robbers' Cave, near the Sea of Galillee, portions of the cranium of a young adult Neandertalian. The next discoveries in Palestine of skeletal remains of this race were made by joint expeditions of the British School of Archæology and the American School of Prehistoric Research in the Wady el-Mughara group of caves. This group is on the western slope of Mount Carmel, near the Crusaders' Castle at Athlit and some 3.2 km. from the Mediterranean shore. Of the three caves excavated two have yielded eleven more or less complete skeletons of the Neandertal race and isolated fragments from several additional skeletons. Ten of the skeletons are from the Mugharet es-Skhūl (Cave of the Kids). A fairly complete female skeleton, a massive lower jaw of a male, and fragments of additional skeletons are from the Mugharet et-Tabūn (Cave of the Oven).

Most of these skeletons were embedded in hard breccia. They were removed in blocks of the enveloping breccia to London, where the task of cleaning has been success-

fully carried on by Mr T. D McCown of the American School under the supervision of Sir Arthur Keith of the Royal College of Surgeons Their combined study of the material is now nearing completion and will appear as a large memoir within a year. The work to date has served to emphasize the fact that, among these individuals the variation, both in kind and degree, is very great If the series of individuals from the Skhūl cave alone had come from as many different sites over a wide area and at different times, anthropologists almost surely would have assigned them to more than one variety of a common extinct race of mankind. Although these Palestine representatives of Neandertal man are actually older than the Neandertalians of western Europe, they stand somewhat closer to Neanthropic man in a morphological sense. Nevertheless according to Sir Arthur and McCown, "it appears unlikely that these ancient Palestinians have given rise to any human forms ancestral to ourselves." The skeletons were found associated with industrial remains of Lower Mousterian type, Lower Levalloiso-Mousterian to be specific.

The third cave of the group—Mugharet el-Wad (Cave of the Valley)—was especially rich in skeletal and industrial remains of a later period, the Mesolithic (Natufian of Palestine). Several score Natufian skeletons were found at Mugharet el-Wad and seventy-five were dug from Mugharet el-Kebarah by our joint excavations. According to Sir Arthur Keith the Natufians were long-headed, with a stature somewhat below the average. One character is the striking development of the leg bones in contrast to the arm bones The Natufians had the habit of extracting the two upper median incisors of their women folk. The removal of one or both of the upper median incisors has been noted by Boule in skulls from the cave of Afalou in the Department of Constantine, Algeria. As artists the Natufians were hardly in the same class as the Magdalenians, yet they took just pride in the carved bone haftings for their sickle blades.

If the relatively large series of skeletal remains from these caves is destined to throw new light on at least two Palestinian races—Neandertal and Natufian—the same may be said of the rich yield of cultural remains from these three caves, especially el-Wad and et-Tabūn. Miss D. A. E. Garrod, of the British School, has practically completed a large memoir on this subject. The culture-bearing deposits of Mugharet et-Tabūn alone have a thickness of over 21 m. (70 ft.). The Tayacian deposits at its base date from the Lower Pleistocene. By building up a composite section of the deposits in all three caves, we have nearly every epoch represented from the Tayacian (a phase of the Lower Paleolithic) to the Bronze Age.

Palestine is at the meeting place of three great land masses, in one of which man first appeared. In spreading to the other two he could hardly have avoided the route by way of Palestine. While our records of early man are yearly increasing in richness there is much yet to be unearthed before we can lay claim to anything approaching completeness. Although it may still be too early to say positively that Asia was the birthplace of man the evidence in favor of this viewpoint outweights that for either Africa or Europe.

To students of the origin and evolution of man a knowledge of geology and paleontology is indispensible in order to interpret aright the age of the deposits in which man's

skeletal and cultural remains, as well as associated fossil fauna and flora, are found. Human origins extend backward into the Tertiary. Even as early as the Lower Pleistocene, man developed both physically and culturally to a point where the term *Homo* can be applied to him; such terms as *Eoanthropus*, *Paleoanthropus*, *Sinanthropus* and *Pithecanthropus* would also seem to be appropriate. His oldest skeletal remains thus far discovered come from both cave and river deposits.

Of these oldest skeletal remains those of *Pithecanthropus erectus*, *Homo heidelbergensis* and *Eoanthropus dawsoni* were found in river deposits, and those of *Sinanthropus pekinensis* in cave deposits. All are datable from associated faunal remains (Lower Pleistocene); and all were found on the periphery of the Euro-Asiatic land mass, *Sinanthropus* near the eastern coast of Asia, *Pithecanthropus* on its southern margin, and Heidelberg man and *Eoanthropus* in western Europe. This geographic distribution from eastern Asia to western Europe tends to support the view now generally held that man originated somewhere in Asia—a view supported also by the results of recent researches which seem to prove that during the Pleistocene period there were no land bridges across the Mediterranean either at Gibraltar or Sicily and Malta. The fossil mammals of Malta and Sicily have Asiatic, or European, rather than African affinities.

Recent discoveries of fossil mammals in the caves of Palestine and Syria indicate that, during the early Pleistocene, the connection of Asia with Africa was as pronounced as that between Asia and Europe. It seems therefore that the Pleistocene mammals of both Europe and Africa had a common source in Asia, migrating north of the Mediterranean into Europe and south of the Mediterranean into Africa.

It is especially fortunate for the prehistorian when human skeletal remains are found associated not only with animal remains but also with artifacts. This fortunate association occurs to a marked degree in the cave of Choukoutien, telling us when *Sinanthropus* lived and how far he had advanced

culturally. He was a maker of stone and bone implements and had a knowledge of the use of fire. This was not much, if any, above the cultural stage reached by Piltdown man (*Eoanthropus*). Many of the stations of the Lower Paleolithic period have yielded cultural remains but no human skeletons; so that our knowledge of fossil man's industry is more complete than is our knowledge of the racial types of fossil man.

When we come to the Middle Paleolithic, generally referred to as the Mousterian epoch, we are now fairly well documented as to both physical and cultural types, especially the latter. The author of Mousterian culture is known as *Homo neandertalensis*, from the skeleton found in 1857 in the Neander valley, not far from Düsseldorf, Germany. But it is well to note here that the first discovery of skeletal remains (adult skull) of this old race was on the Mediterranean at Gibraltar in 1848. And in 1926 Miss Dorothy Garrod unearthed the skull of a five-year-old Neandertal child from a rock shelter near the quarry where the Gibraltar skull had been found. If we follow the northern shore of the Mediterranean eastward we come to other sites which have yielded skeletal remains of Neandertal man. In a gravel pit at Saccopastore, near Rome, an early type of Neandertal man was found in 1929. The same site has just yielded a second individual of the same race. This skull was unearthed by Professor Breuil and A. C. Blanc and is incomplete, but fortunately contains parts lacking in the first skull. Both belong to the Chapelle-aux-Saints type. Professor Sergio Sergi who is still to make a final report on the first skull is to report also on the second.

In this connection it should be noted that no skeletal remains of the Neandertal race have been found along the southern shore of the Mediterranean. But a type not unlike the Neandertal has been found at Broken Hill in Rhodesia. On the other hand Neandertal man dwelt not only along the northern shore but also inland; for his skeletal remains have already been found at nearly a dozen sites from France and Belgium in the west through Germany and Yugoslavia to the Crimea in the east.

Returning now to Palestine and Syria which long have been such rich fields for the historian and protohistorian, we find they can be classed among the richest fields for the prehistorian. By the early sixties when Lartet and Christy entered upon their record-making discoveries in the Dordogne and when firm foundations were being laid for prehistory in western Europe, the near east was still a prehistoric *terra incognita*. In 1870 the Abbé Richard found chipped flints near Jericho which he explained as being the tools used by Joshua for performing the operation of circumcision. However before the end of the century Palestine seemed in a fair way to profit by and follow the example of prehistoric research in western Europe. Now practically every phase of prehistory as revealed in western Europe has its counterpart in Palestine; progress in this field has been especially rapid since the first discovery (1925) in Palestine of the skeletal remains of fossil man.

In the spring of 1925 F. Turville-Petre, for the British School of Archæology in Jerusalem, began excavations in the Mugharet ez-Zuttiyeh (Robbers' Cave), near Tabgha on the Sea of Galilee. Here he found portions of the cranium of a young adult Neandertalian, probably female. The parts include the frontal, right wing of the sphenoid, right cheek bone, also a portion of the upper jaw and nasal bones. The skull fragment was in close association with a typical Mousterian industry, including scrapers, points and occasional hand-axes. Sutures of a young adult of modern races are rarely fused. However in this skull the two nasal bones are firmly fused, as is also the portion of the upper jaw to the cheek bone. The early obliteration of these two sutures is normal to the young gorilla and chimpanzee. The Galilee skull is preserved in the Museum of the Department of Antiquities, Jerusalem.

The discovery of the Galilee skull did much to quicken interest in Palestinian prehistory; it may have been instrumental in bringing to Jerusalem and Beirut the following year (1926) an International Congress of Archæology. Mrs.

MacCurdy and the writer attended this Congress and saw not only the Galilee skull but also the cave from which it came, as well as the neighboring Mugharet el-Emireh. We visited other prehistoric sites including Sambariyeh, near Mutullah on the headwaters of the Jordan, where we found some fine Acheulian hand-axes. This initiation in the Palestine field led us to accept with alacrity in 1929 the invitation to carry on field expeditions jointly with the British School of Archæology in Jerusalem. We shall attempt to sketch briefly some of the results of seven seasons of joint excavations in the Wady el-Mughara, south of Haifa. Six of these were directed by Miss D. A. E. Garrod of the British School and one by Mr. Theodore D. McCown of the American School.

The Wady el-Mughara

The Wady el-Mughara (Valley of the Caves) cuts through a limestone escarpment on the western slope of Mount Carmel, some 3.2 km. from the Mediterranean shore and 5.6 km. southeast of the Crusaders' Castle at Athlit. The caves are in the bluff south of the cut (Pl. I). The Mugharet es-Skhūl (Cave of the Kids) faces north toward the Valley; the Mugharet el-Wad (Cave of the Valley) and Mugharet et-Tabūn (Cave of the Oven) face west toward the coastal plain. The accidental discovery of a bone carving in the talus below Mugharet el-Wad in November, 1928, by Mr. Lambert of the Department of Antiquities, first focussed attention on this group of caves which has more than fulfilled its promise of productivity.

Mugharet el-Wad. The joint excavations were begun at Mugharet el-Wad in the spring of 1929. This cave was particularly rich in both skeletal and cultural remains of the Mesolithic period (Natufian of Palestine). There are two Natufian levels in this cave—upper and lower. The Upper Natufian is noted for the abundance of microgravers; the Lower Natufian is characterized by the preponderance of sickle blades and the abundance of and variety of bone objects, including carved bone haftings for sickle blades.

The Natufian, a term first applied to the Mesolithic of Palestine by Miss Garrod, receives its name from the Wady el-Natuf, 27 km. northwest of Jerusalem. In this valley is situated the cave of Shukbah which has an Upper Natufian level. With the help of two students from the American School this cave was partially excavated by Miss Garrod in the spring of 1928. Since 1929 our joint expeditions have found Lower Natufian in the Mugharet el-Kebarah, a short distance south of the Wady el-Mughara group of caves. The Natufian occurs likewise at other Palestine sites including Erq el-Ahmar and el-Khiam, both south of Jerusalem. Below the Lower Natufian of the Mugharet el-Wad are layers of Upper, Middle and Lower Aurignacian, and below these a deposit of Upper Levalloiso-Mousterian age. A few fragments of human skeletal remains were found in the Aurignacian deposits. On the other hand the Lower Natufian deposits were exceedingly rich in skeletons (eighty-seven) of a Mesolithic race. Forty-five skeletons of this race were unearthed at Shukbah and seventy-five at Kebarah.

According to Sir Arthur Keith the Natufians were long-headed with a cephalic index varying from 72 to 78; their faces were short and wide; their chins were not prominent but were masked by the fullness of the teeth-bearing parts of the jaw; they were prognathous, the sub-nasal prognathism being marked; their nasal bones were not narrow and high but formed transversely a wide, low arch. The stature was low, very few of the men exceeding 1.65 m. (5 ft., 5 in.). One striking character is the strong development of the leg bones in contrast to the arm bones. The thigh bones have a prominent *linea aspera;* the tibiæ are platycnemic, and in more than half of the humeri there is a perforation of the *olecranon fossa.* The Natufians had the habit of extracting the two upper median incisors of the females, examples of this mutilation having been found at Mugharet el-Wad as well as at Shukbah and Kebarah. The removal of one or both of the upper median incisors has been noted by Boule in skulls from the cave of Afalou in the Department of

Constantine, Algeria; these date from a period not much, if any, older than the Natufian of Palestine.

Neandertal Man of the Wady el-Mughara. Of far greater importance than Turville-Petre's discovery of the Galilee skull were the discoveries of Neandertal skeletons, some of them fairly complete, in two of the three Wady el-Mughara caves near Athlit: Mugharet es-Skhūl (Cave of the Kids) and Mugharet et-Tabūn (Cave of the Oven). The oldest layer in the Mugharet el-Wad contained the industry of Neandertal man; as for his skeletal remains only a molar was found in this layer; on the other hand the Cave of the Kids, the smallest of the three, yielded skeletal remains of ten Neandertalians.

Cave of the Kids. This small cave had been assigned previously to Theodore D. McCown of the American School who, in the absence of Miss Garrod, was Director of excavations in 1931. Before the close of the season he found the skeleton of a child about three and a half years old (No. 1 of the series from Skhūl).

Of the child's cranium the parts present are: the parietals, right temporal and occipital, the frontal bone and the petrous portion of the left ear (Pl. II). The greater part of the corpus and the anterior portion of the left ascending ramus of the lower jaw remain. The face and the upper jaw are missing, but from the upper jaw there were rescued a few teeth of the milk dentition and crowns of the unerupted permanent molars, a permanent canine, a lateral and a median incisor. Of the upper limb bones one radius and portions of both humeri were found; fortunately each one of the latter contains parts absent in the other. The vertebral column and ribs are partially preserved. The pelvis is represented by portions of the innominate bones and the uppermost segment of the sacrum. The left leg is nearly complete; of the right leg only the shafts of the bones remain. Present from the left ankle and foot are a part of the talus, part of the calcaneum and a complete set of the metatarsal bones.

During the season of 1932 the skeletal remains of eight more Neandertalians were found in the Skhūl cave. They

are listed here in the order of their finding. Number II of the series is an adult, probably a female. The skull is fragmentary; a portion of the frontal includes the root of the nose and some two-thirds of the superior border of the right orbit; the torus is characteristic of the Neandertal type. The symphysial portion of the lower jaw is preserved, the chin prominence being unmistakable; the bone as a whole is slight in build. Of the arm bones the head and neck of one radius, the proximal ends of both ulnæ and the diaphyses of both humeri are present. The condition and position of all these fragments lead unmistakably to the conclusion that the burial had been disturbed at some unknown time in the past.

The situation in which the fragments of Skhūl III were found is perplexing. These are of an adult. The distal half of the shaft of the left femur was lying parallel with, and close to, the proximal parts of the shafts of its corresponding tibia and fibula; this flexed left leg was buried in an alcove in the rock wall at the southeast corner of the terrace. The position of this left leg indicates that the body originally must have been placed partly in the alcove, but extending largely on the terrace proper. These leg fragments are the only traces of this individual that were found anywhere on the site. The bones are robust and the femur has a well developed *linea aspera.*

Skhūl IV is the most complete of all the adult individuals found on this site. The cranium and lower jaw lay close to the rock floor and the weight of the overlying deposit crushed the bones to a considerable extent. Fortunately the face escaped; the prognathism of the upper jaw is pronounced and the nasal aperture is broad with no sharply defined sill. The bones of the left arm are fairly complete; the head and upper part of the shaft are missing in the right humerus. The major part of both hands and wrists are present, the right one lying palm uppermost, the left lying immediately in front of and partly underneath the chin. The left scapula is nearly complete, but the right one has been destroyed. While the vertebral column is fragmentary, a majority of the ribs on

both sides are preserved. The collar bones are fragmentary; the manubrium has disappeared, but the rest of the sternum is almost intact. The two innominate bones are nearly complete, while the sacrum is represented by only a small piece of the dorsal surface of the bone containing the inferior opening of the sacral canal. The leg bones are very well preserved; this is especially true of the tarsus and metatarsals. These bones of the ankles and feet are in more perfect condition than those of any other Neandertalian unearthed anywhere to date (Pl. III).

Skhūl V is another remarkably well preserved individual. The skull is almost complete, the postmortem damage to the left side of the frontal and the left border of the orbit having been effectively repaired. The base of the cranium the portion usually the first to suffer, is only slightly damaged. On the other hand the face is almost entirely gone, but the alveolar margin of the upper jaw, containing all the teeth, is complete; and the bony floor of the palate, although cracked and fissured, retains its normal position. The lower jaw is complete and the lower incisors and canines meet those in the upper jaw edge-to-edge (Pl. IV). The two humeri are almost intact, but the articular ends of the bones of the forearm have decayed. Of the two collar bones the right one is the more complete. The ribs are fragmentary. Of the vertebral column the best preserved vertebræ are the seven non bifid cervicals. All that remains of the pelvis is the right ilium. The head of the right femur, with neck and upper half of the shaft, is cemented into the acetabulum by breccia. Nearly the whole of the shaft, with part of the distal articular end, of the left femur is preserved. The left tibia extends from the damaged condylar surfaces to a point just short of the distal end. The left fibula is represented by several crushed parts of the shaft. Of the foot only one talus and one first metatarsal were found.

Skhūl VI was found in the center of the terrace embedded in very hard breccia; the parts recovered were in a scattered condition covering a space of about a square meter. The

cranium was crushed and fragmentary, the principal remaining parts being the left temporal, the occipital and portions of the adjacent left parietal. Of the lower jaw there remain most of the left ramus and a small part of the adjacent corpus containing the third molar. Of the rest of the skeleton there were retrieved the left femur which is nearly complete, the shaft of the right femur, two-thirds of the shaft and the distal end of the left tibia with its corresponding talus, calcaneum, navicular and cuboid, also two fragments of the left radius and ulna. There are a number of other fragments not yet identified.

Skhūl VII was a crouched burial on the right side. The skull lay on its right side, but was so crushed that any reconstruction of the parts is impossible. Enough of the frontal bone, the parietals and left temporal remain to give some data for comparison with the other, less damaged crania. The position of the hands in front of the face is like that of the hands in Number IV, but the lower limbs had been tightly flexed with the knees drawn upward and pressed against the body. The two humeri are incomplete, as are likewise the right radius and ulna, but the left forearm bones are little damaged. The pelvis and leg bones are badly crushed and incomplete; of the latter only the right femur and tibia remain. In length and slenderness the bones of this skeleton closely resemble those of the female skeleton from the Tabūn cave.

Skhūl VIII is fragmentary. The parts recovered belong to a child some eight to ten years of age. They include the tibia and fibula, tarsus and metatarsals of the left leg and foot. The right leg is represented by the shaft of the femur and the distal two-thirds of the shaft of the tibia, with distal epiphysis and the talus still in position.

Number IX, an old adult, was found in extremely hard breccia just above the rock floor of the terrace; it was the last skeleton discovered at Skhūl in 1932. When later in the laboratory, the hard matrix was cut away (1934 and 1935), there were revealed the major part of the cranium, several

ribs, the spine of the left scapula and part of the left half of the pelvis with the head and upper portion of the shaft of the left femur still socketed in the hip joint. Occupying the space which should have contained the greater part of the remainder of the skeleton, was the nearly complete, much crushed skull of a large bovine animal. Apparently at some time subsequent to the human interment, this ox skull was buried, the excavation made to receive it having destroyed the greater part of the human burial.

Skhūl X has been added since the end of the season of 1932. It is based on the symphysial portion of the corpus of the lower jaw of a child between four and five years of age. This fragment was discovered in the laboratory, and in the block which contained Number VII, an adult. It lay in front of and below the adult's skull, and near it was the distal end of a right humerus belonging to the same child. In the piece of lower jaw the milk dentition was still in the functional stage, but an oblique fracture across the piece reveals that the crowns of the permanent dentition are already well-formed, somewhat in advance of those of Skhūl I. Four crowns of the upper permanent dentition were found near the lower jaw.

Mugharet et-Tabūn. Two individuals of the Neandertal race are well represented from this cave. Of these two the remains of a female about thirty years old is the more complete. The vault and right side of the cranium have been reconstructed from about fifty pieces. The left temporal, with part of the occipital, including the basilar portion, forms a separate section which has not been joined to the remainder of the cranium in order to facilitate the casting of the specimen. The face is preserved in part, the maxillary arch being complete except for the left M-3, and the ascending process of the maxilla on the right side articulates with the frontal. The lower jaw would be practically complete were it not for the loss of both condyles (Pl. V).

The existing vertebræ are all fragmentary, but the ribs on the left side are in good condition. The left scapula preserves the intact axillary border with the glenoid articulation, part

of the coracoid and the complete acromion with the root of the spine. The right scapula is missing. The sternum and the two clavicles are incomplete. The bones of the left arm are nearly perfect. The carpus lacks the os multangulum minus, and several of the metacarpals have been slightly damaged. As for the right arm the humerus lacks the distal end, the radius has been destroyed and only a small fragment of the ulna shaft remains. The bones of the wrist and hand are missing.

Of the pelvis there remains the anterior half of the left ilium. Although the right femur is complete its distal end has been crushed. The left femur is so badly shattered as to make reconstruction impossible. The two tibiæ are fairly well preserved. The right fibula is complete except for the proximal end: the left is represented by some 15 cm. of the shaft. The right tarsus is in good condition as are the corresponding metatarsals (Pl. VI). The left tarsus is not so complete, but the talus is intact, as is also the first metatarsal.

All that was found of the second individual from Tabūn was its massive lower jaw (Pl. VII). The female skeleton and this lower jaw were both found in Deposit C (Lower Levalloiso-Mousterian) of the Tabūn cave, the skeleton near the top of the deposit and the lower jaw 90 cm. further down. In addition this same Deposit C has yielded a number of bone fragments and isolated teeth representing perhaps half a dozen individuals. The principal pieces are: (1) a fragment of an adolescent maxilla and six teeth of the right side belonging to it; (2) the distal end of a right radius similar in size to that of the female skeleton; (3) the fragment of a femur shaft.

From older deposits (Acheulian) of the same cave have come two interesting specimens. One is a heavily mineralized mid-portion of the shaft of a left femur; the other is a single, very worn, molar tooth. Unfortunately these remains are too scanty to permit of drawing any conclusions concerning the physical characters of the race which lived in Palestine during Acheulian times.

The provisional statements made by McCown and Sir Arthur Keith which were published in Bulletin No. 10 of the American School of Prehistoric Research, regarding the general morphology and systematic position of these skeletons from Palestine, need no essential revision. Their work on this material during the past eighteen months has, however, served to emphasize the fact that among these individuals the variation, both in kind and degree of development, is very great. A good example is seen in the difference between the primitive lower jaw of the female from Tabūn and the less primitive male lower jaw found in the same deposit of the same cave but at a greater depth. If the series of individuals from the Skhūl cave alone had come from as many different sites over a wide area and at different times, anthropologists almost surely would have assigned them to more than one variety of a common extinct race of mankind.

The female skeleton from Tabūn is nearer to what has been looked upon as the Neandertal type than any of the others from these two caves. While all the others bear undoubted marks of the Neandertal breed, they bear at the same time a large number of physical characters which point in the direction of a more modern human type. Although these Palestine representatives of Neandertal man are actually older than the Neandertalians from western Europe, they stand somewhat closer to Neanthropic man in a morphological sense. Nevertheless according to Sir Arthur and McCown, "it appears unlikely that these ancient Palestinians have given rise to any human forms ancestral to ourselves."

The many months of patient work devoted to cleaning and removal from hard breccia of this splendid series of fossil human skeletons have been fully justified, in that all of the specimens have been extracted without suffering any considerable damage. For this achievement Sir Arthur and McCown, together with their staff of able assistants, deserve hearty congratulations. The reproduction of the specimens is now under consideration; it is planned to effect arrangements so that plaster casts of the crania, lower jaws and the

more complete parts of the rest of the skeletons will be available by the time the large memoir now nearing completion is off the press.

The Cultural Remains of Prehistoric Man in Palestine. To complete the story of prehistoric man in Palestine the study of his cultural remains must keep pace with that of his physical remains, and this is true in so far as the joint excavations of the two schools in question are concerned; in fact the cultural sequence is even more complete than is the sequence of human physical types. Miss D. A. E. Garrod has had charge of this phase of the work and her large memoir on the subject is now practically finished.

The culture-bearing deposits of the Tabūn cave alone have a thickness of over 21 m. (70 ft.). The Tayacian deposits at its base date from the Lower Pleistocene. By constructing a composite section of the deposits in all three caves—Tabūn, Skhūl and Mugharet el-Wad—we have practically every epoch represented from the Tayacian to the Bronze Age (Pl. VIII). In this section, slightly modified from the one previously published (Bulletin No. 10, A.S.P.R.), the overlap between Mugharet el-Wad and Tabūn cave makes it possible to build up the section with as much confidence as if the complete sequence had been actually present in a single cave.

The Tayacian deposit (*G*) at Tabūn rests on the bed rock and is the oldest archeological level thus far found in any Palestinian cave. It occurs also at Umm Qatafa in the Judæan desert where it was found by Neuville in 1932. The Abbé Breuil was the first to point out the identity of this Palestinian industry with the Tayacian of the Dordogne (France). It is characterized by an abundance of small utilized flakes, a majority with plain striking platforms, also by a great scarcity of true implements with secondary working. According to Breuil the Tayacian is derived from the Clactonian.

The Lower Acheulian of Layer *F* is preëminently an industry of hand-axes, flake-tools being absent at its base, but appearing in relatively small numbers towards the top.

A similar industry occurs at Umm Qatafa where hand-axes predominate.

Tabūn *E* may be divided into four phases, all Upper Acheulian. The industry has many points in common with the Upper Acheulian from river deposits in northern France. Miss Garrod finds that the thick scrapers with resolved flaking which are so abundant in Tabun *E* (Pl. X) do in fact occur as a typical component of the Acheulian culture of western Europe. The hand-axes of Layer *E* include many true Micoquean forms especially in the horizon *Ec*, a stage roughly comparable with the top layer of La Micoque itself (Pl. IX).

Above the Upper Acheulian of Tabūn come two phases of Lower Levalloiso-Mousterian (*D* and *C*) and the Upper Levalloiso-Mousterian (*B*). The passage from Tabūn *C* to *B* is marked by the disappearance of *Rhinoceros merckii* and hippopotamus. The skeletal remains of Neandertal man were found in Tabūn *C* and Skhūl *B*, the latter corresponding in time with Tabūn *C*. The different stages of the Levalloiso-Mousterian have been found by Neuville in a number of Palestine sites, notably in the cave of Jebel Qafseh, near Nazareth, where four human skeletons, corresponding roughly in age with those from Skhūl and Tabūn, have been discovered (not yet published). The Levalloiso-Mousterian of Palestine has affinities with the Middle Paleolithic of Egypt, in which the Levallois flakes predominate to the exclusion of classic Mousterian types; it differs from that of Europe, in which industries of Levalloisian tradition alternate with those of true Mousterian type, as pointed out by Miss Garrod (Pls. XI and XII).

The scene shifts with the arrival of the Upper Paleolithic; Palestine is assimilated to Europe and her contact with Egypt and northern Africa apparently ceases. The Lower Aurignacian is better represented at Jebel Qafseh than at Mugharet el-Wad *F*. It is in the Châtelperron tradition, but delicate and less primitive than is the Châtelperron of western Europe. Among its original features there should

be mentioned the presence of a special type of triangular flint point with thinning at the base; this type occurs also but not frequently in the Aterian of northern Africa. Miss Garrod has named it the Emireh point from the Galilean cave of el-Emireh where it was first found in situ by Turville-Petre.

Of the two Middle Aurignacian horizons at el-Wad *E* is characterized by the presence of a special type of small, spiky flint point with fine retouch which is found also in European sites including Krems in Austria and Font-Yves in France (Pl. XIII). The industry of the succeeding layer (Wad *D*) with its two scratcher types—keel and nose—is a well-developed, classic Middle Aurignacian, although it cannot be considered as the equivalent of any one of the subdivisions of this stage in western Europe (Pl. XIV). Layers corresponding to el-Wad *E* and *D* were found by Turville-Petre in excavations carried out for the two Schools in the Mugharet el-Kebarah, near Zichron Jacob, a short distance south of the Wady el-Mughara, and by Neuville in various sites, of which the most important is Erq el-Ahmar in the Judæan desert. These discoveries in Palestine of a highly developed, unmixed industry of Aurignacian and Solutrean age points unmistakably to Asia as the center of diffusion for Aurignacian culture.

The Upper Aurignacian of el-Wad *C* which presumably takes the place occupied by the magdalenian in western Europe was originally referred by Miss Garrod to the Capsian, a view which she soon had to abandon; for this very rough and peculiar industry, with its abundance of polyhedric gravers, cannot be compared with any other Upper Paleolithic facies yet known. While to a certain extent it has the aspect of a degenerate survival of the Middle Aurignacian, the reappearance of the Châtelperron point, absent since the beginning of the Upper Paleolithic, suggests the arrival of outside influences (Pl. XV).

The Natufian (el-Wad *B2* and *B1*) is definitely original notwithstanding certain general features that are common to

a large majority of Mesolithic industries (Pl. XVI). Natufian art cannot be linked with the Magdalenian of Europe: nor does it have predynastic affinities. About Natufian origins we still have much to learn. Future excavations, especially in Anatolia, may be expected to shed much needed light on the problem. While Miss Garrod recognizes two Natufian horizons at el-Wad, Neuville believes he has sufficient evidence from other sites to make a fourfold division of the Natufian, his Natufian I corresponding to *B2* at el-Wad and the notched arrowhead appearing in his Natufian IV. The Upper Natufian is noted for the abundance of micrograyers. The Lower Natufian is characterized by the preponderance of sickle blades over lunates and crescents, and by the abundance and variety of bone objects. At Mugharet el-Kebarah the level next below the typical Lower Natufian and just above the uppermost Middle Aurignacian layer, also had a Mesolithic appearance, microliths greatly predominating over normal-size implements.

There is still much to be done toward the establishment of a distinct correlation among the various archeological layers and sites. A further study must also be made of the geological deposits outside the caves. Regarding the latter Picard has made a good beginning in the Jordan valley where he finds evidence of two main Pleistocene Pluvials (*A* and *B*), separated by an interpluvial marked by volcanic activity, and followed by a period of increasing dessication (*Jungdiluvium*), with a possible slight pluvial phase before the beginning of the Bronze Age. Miss Garrod identifies Picard's *Jungdiluvium* with a fair degree of certainty at Mugharet el-Wad where the gradual replacement of deer by gazelle in the Upper Paleolithic layers suggests increasingly dry conditions from the Lower Aurignacian onward (the animal remains from Wady el-Mughara have been identified by Miss D. M. Bate, Museum of Natural History, London). The evidence from the underlying layers is not so clear. No animal bones were found in Tabūn *G* while few were found in *F* and these give no clear climatic clues. But at Umm

Qatafa, the lower layers of which correspond to Tabūn *F*, the fauna was holarctic and did not point to particularly damp conditions. On the other hand Tabūn *E* contained an abundant fauna including *Rhinoceros merckii* and hippopotamus, and pointing to a warm, wet climate. These conditions persist throughout Tabūn *D* and *C*, but in *B* rhinoceros and hippopotamus both disappear and two species of deer, *Cervus elaphus* and *Dama mesopotamica*, are very numerous—a fact indicating continued high precipitation but a lower temperature. Judging from the fauna we thus have evidence of rather dry conditions in the early part of the Upper Acheulian, followed by a long, rainy period lasting until the end of the Upper Levalloiso-Mousterian. At first sight this would appear to correspond roughly with Picard's Interpluvial and Pluvial *B*. Additional light on the problem of correlation may be expected from a further study of the Pleistocene deposits in Palestine and Syria.

Plate I. Wady el-Mughara. General view at the close of excavations. At the right, Mugharet et-Tabun; in the center, Mugharet el-Wad; at the left, M. es Skhul

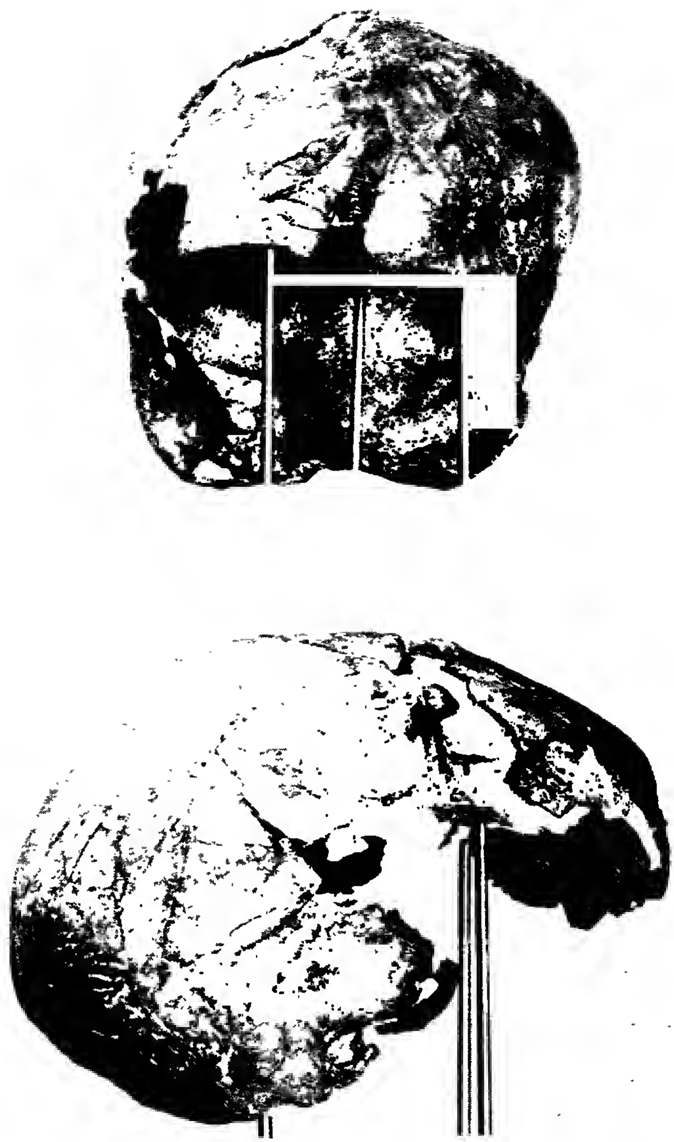

PLATE II. Cranium of Skhūl No. I, a child between 3 and 4 years of age. Neandertal race

Plate III. Skeleton of Skhūl IV, adult. The lower part of right leg and right foot have been removed to show the left ankle and foot. Neandertal race.

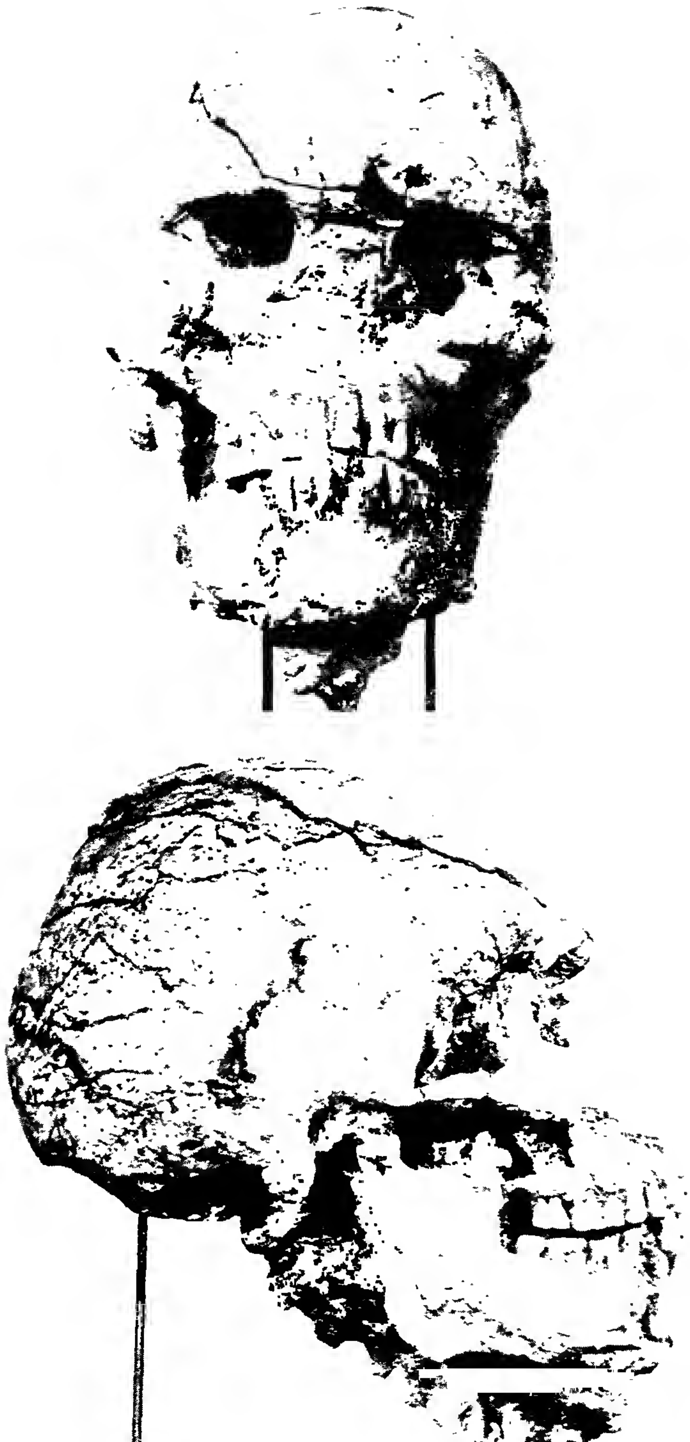

PLATE IV. Skull of Skhūl V, adult. The upper and lower incisors and canines meet edge-to-edge. The rest of the skeleton is fairly well preserved. Neanderthal race.

PLATE V. Tabūn I, female about 30 years old. Note absence of chin The rest of the skeleton is fairly well preserved. Neandertal race

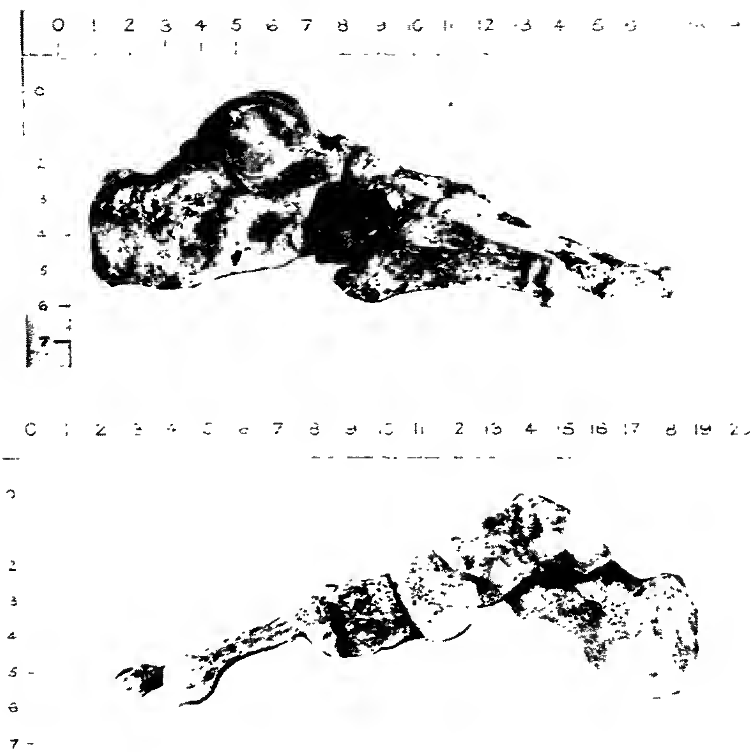

Plate VI Tabūn I, two views of the right foot.

Plate VII. Tabūn II, adult. Two views of the lower jaw. Pronounced chin. Neandertal race.

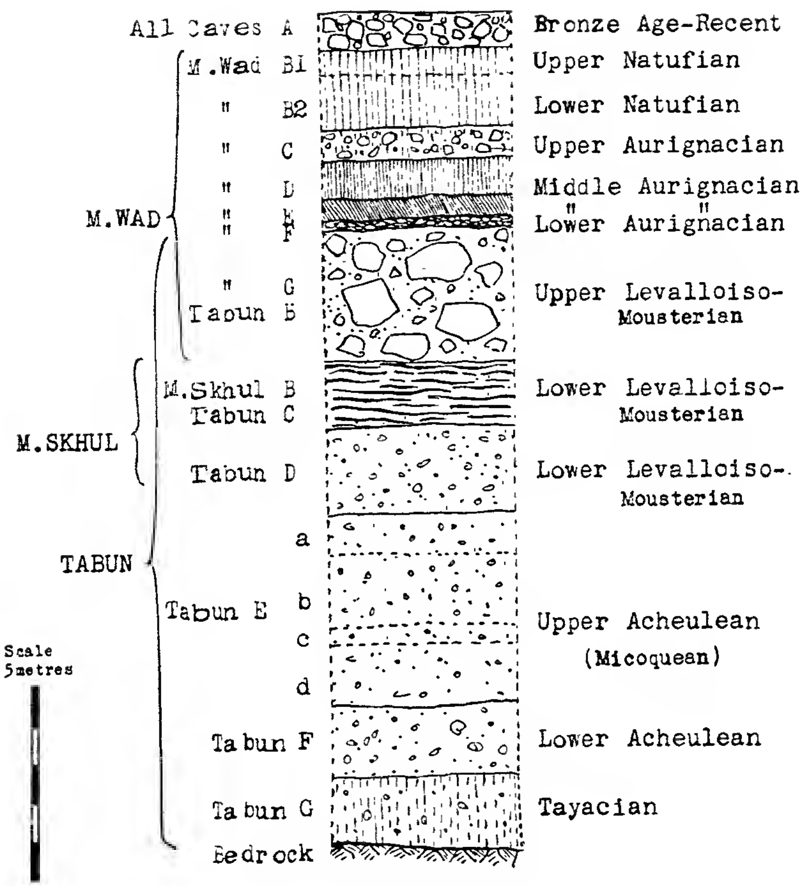

PLATE VIII. Composite section of the layers in the three caves of the Wady el-Mughara.

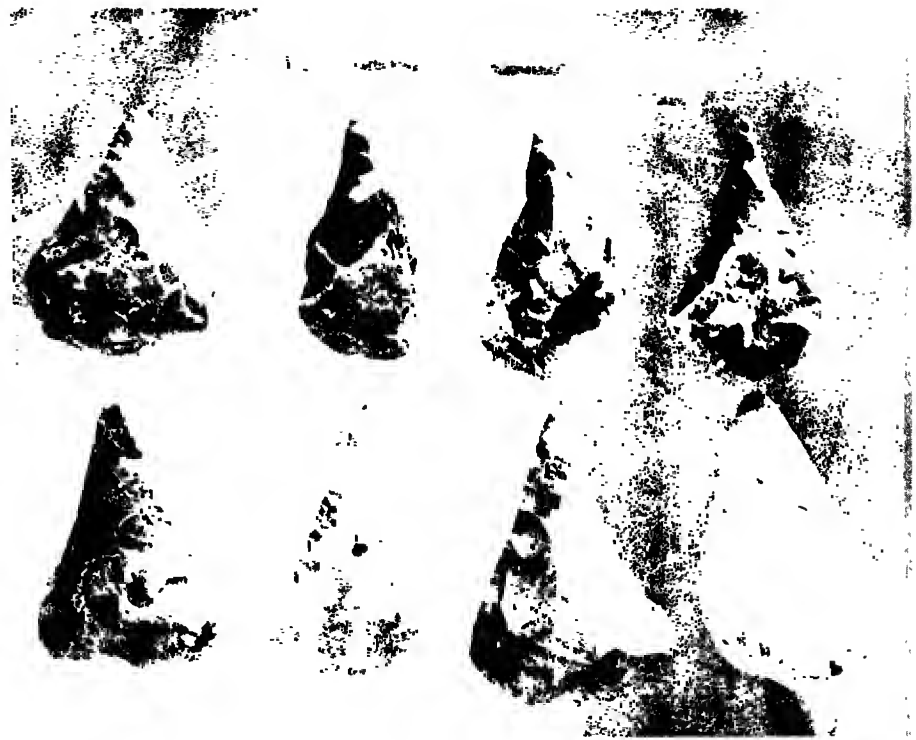

PLATE IX. Upper Acheulian hand-axes of La Micoque type, from Layer *Ec*, Mugharet et-Tabun.

PLATE X. Upper Acheulian scrapers (above) and hand-axes (below), from Layer E^1, Mugharet et-Tabūn.

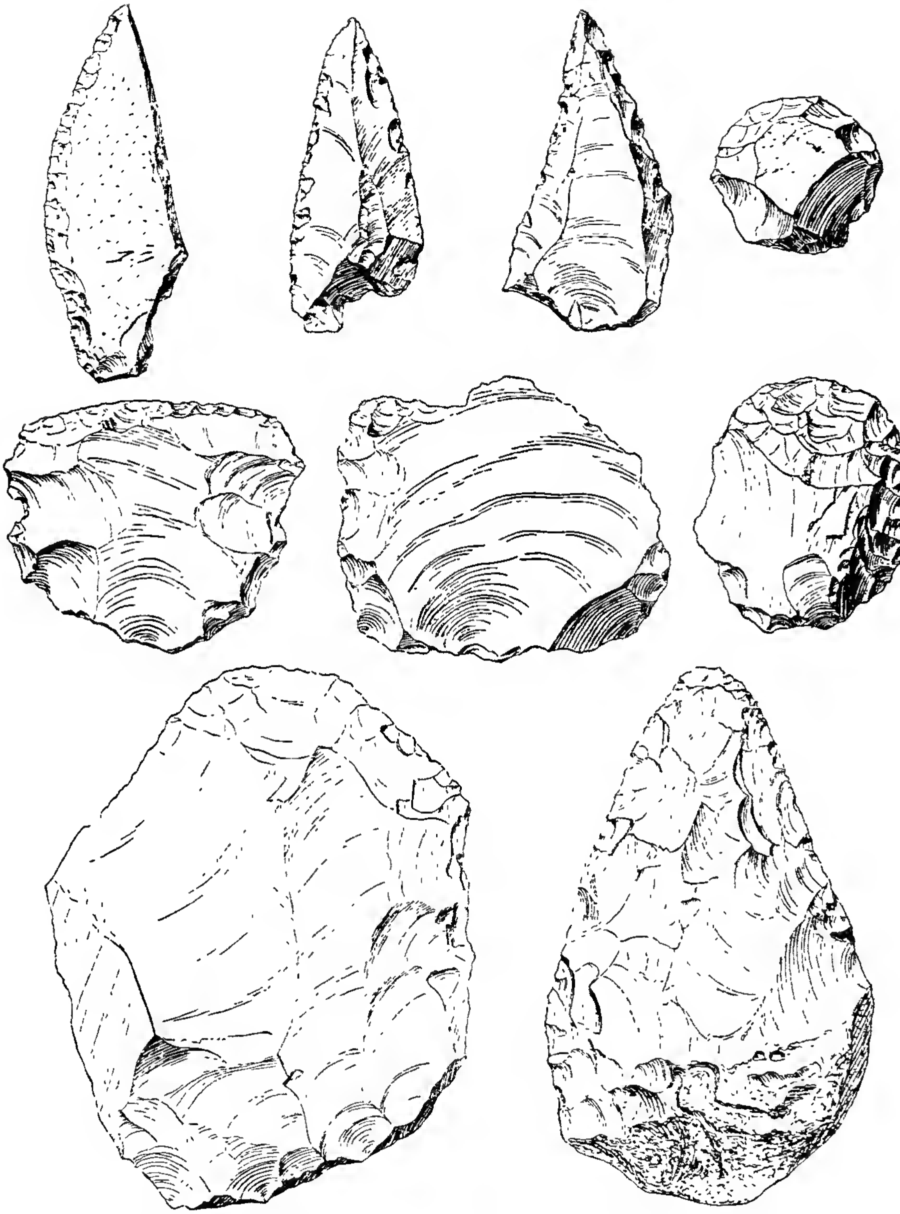

PLATE XI. Lower Levalloiso-Mousterian implements from Layer *B* (the layer in which the ten Neandertal skeletons were found) of Mugharet es-Skhūl.

PLATE XII. Upper Levalloiso-Mousterian implements from Layer *B* of M. et-Tabūn.

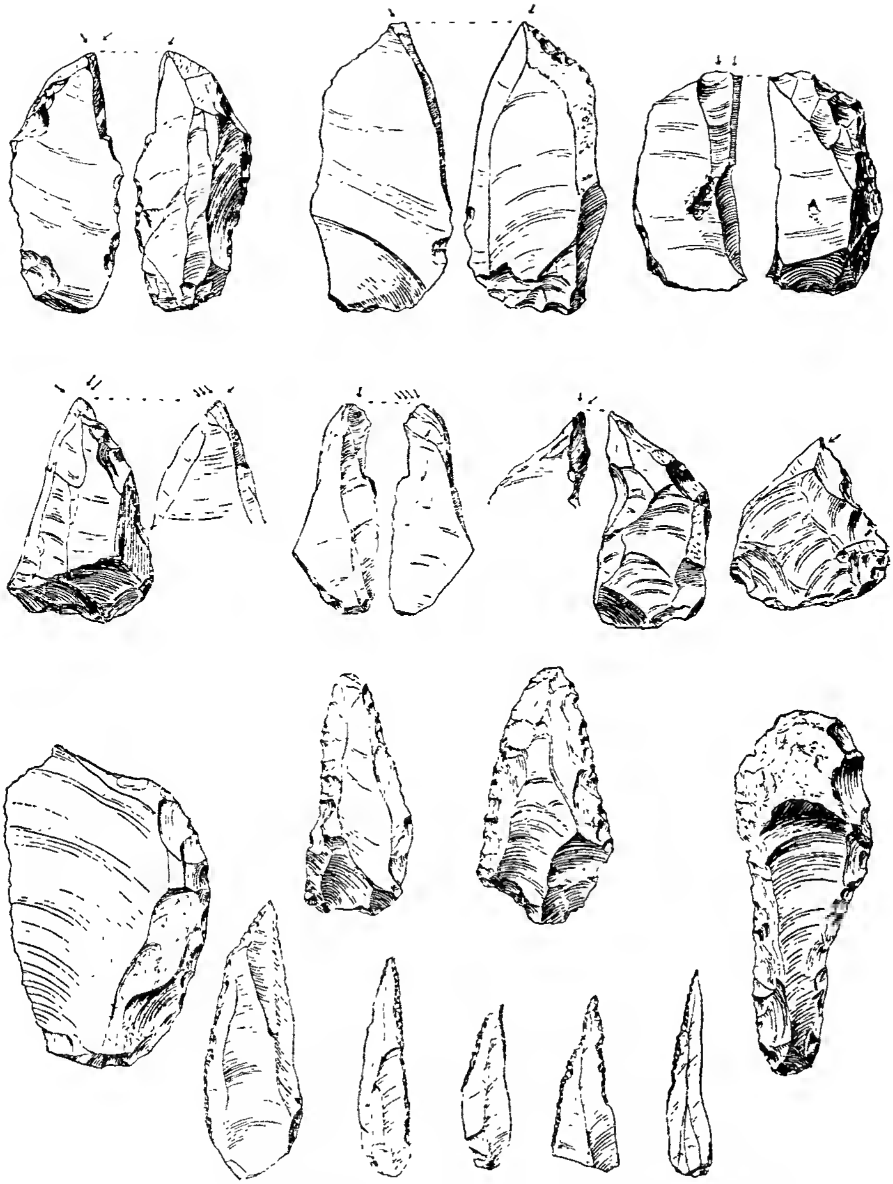

PLATE XIII. Middle Aurignacian implements from Layer *E* of M. el-Wad.

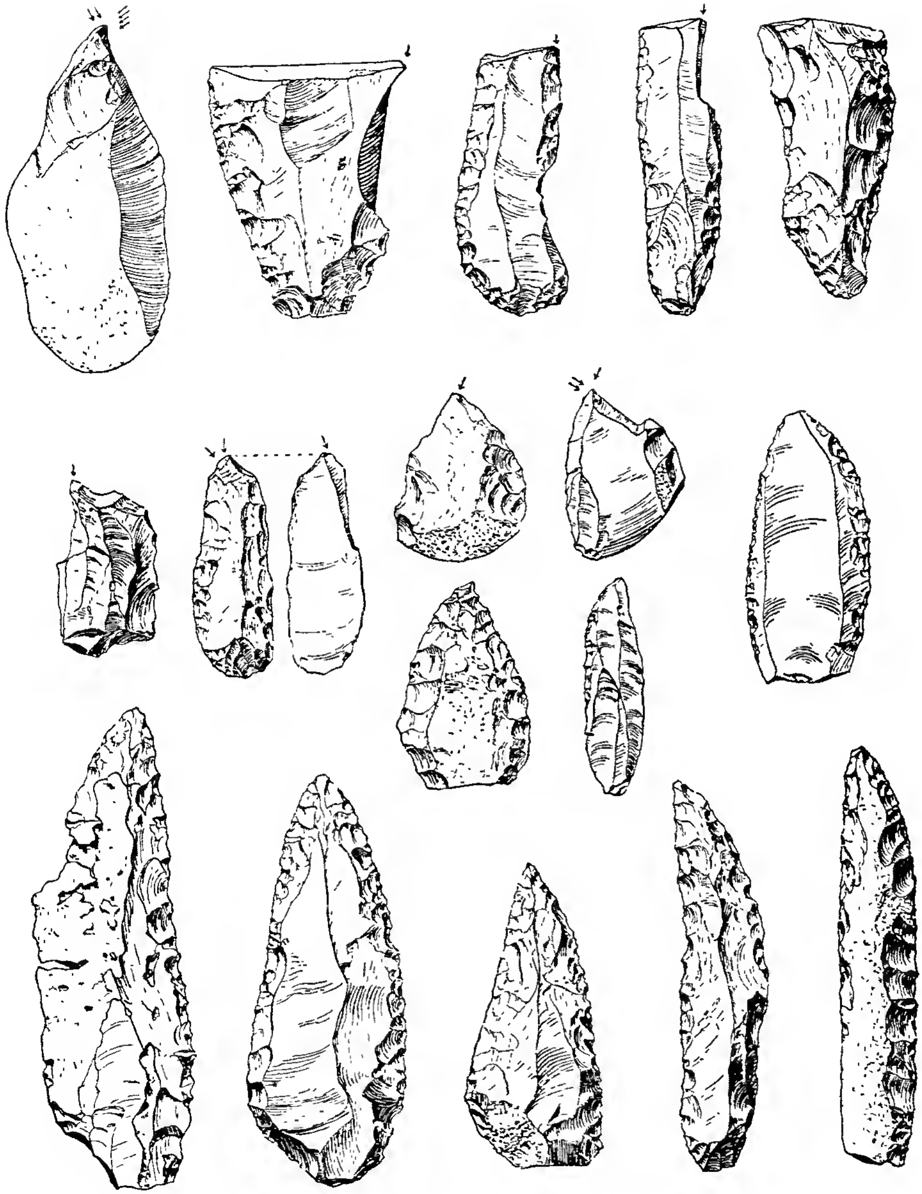

PLATE XIV. Middle Aurignacian implements from Layer *D* of M. el-Wad.

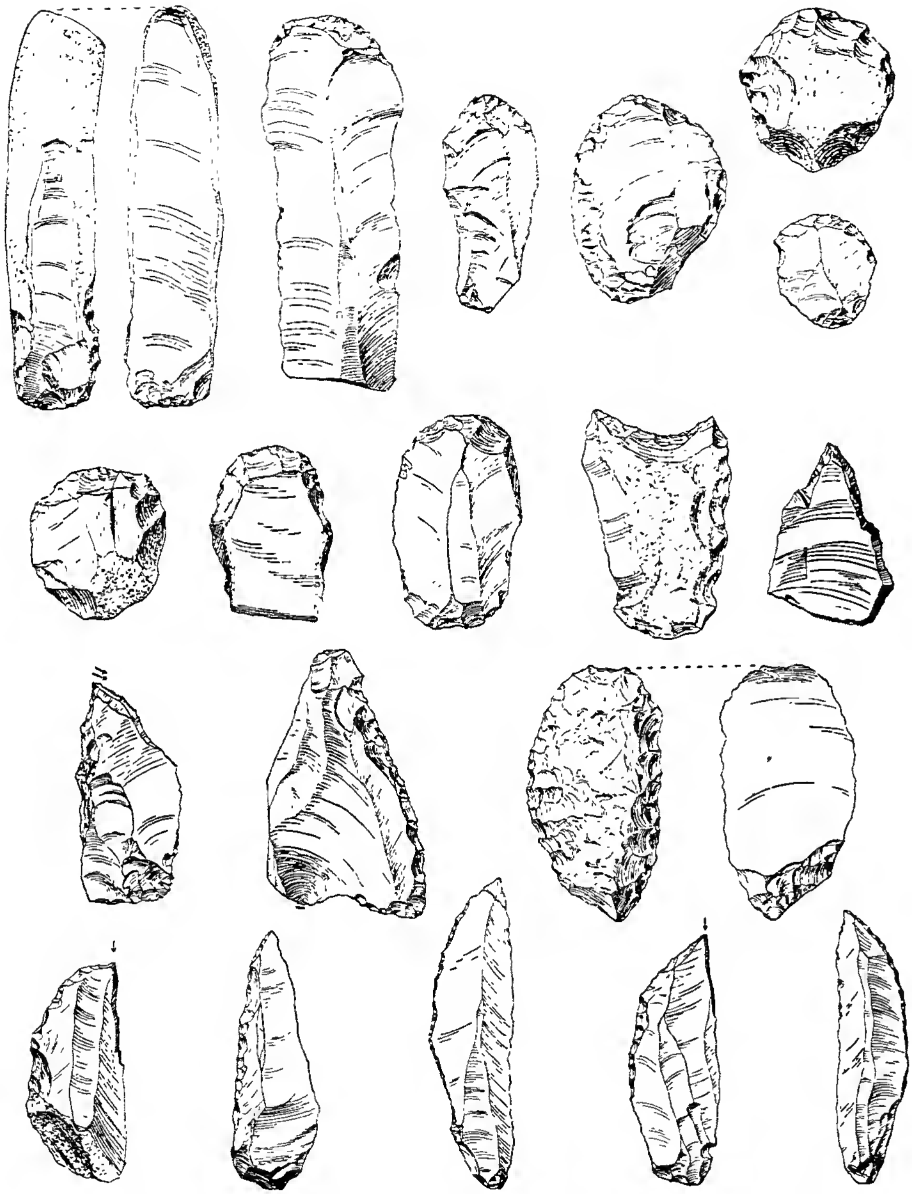

Plate XV. Upper Aurignacian implements from Layer *C* of M. el-Wad.

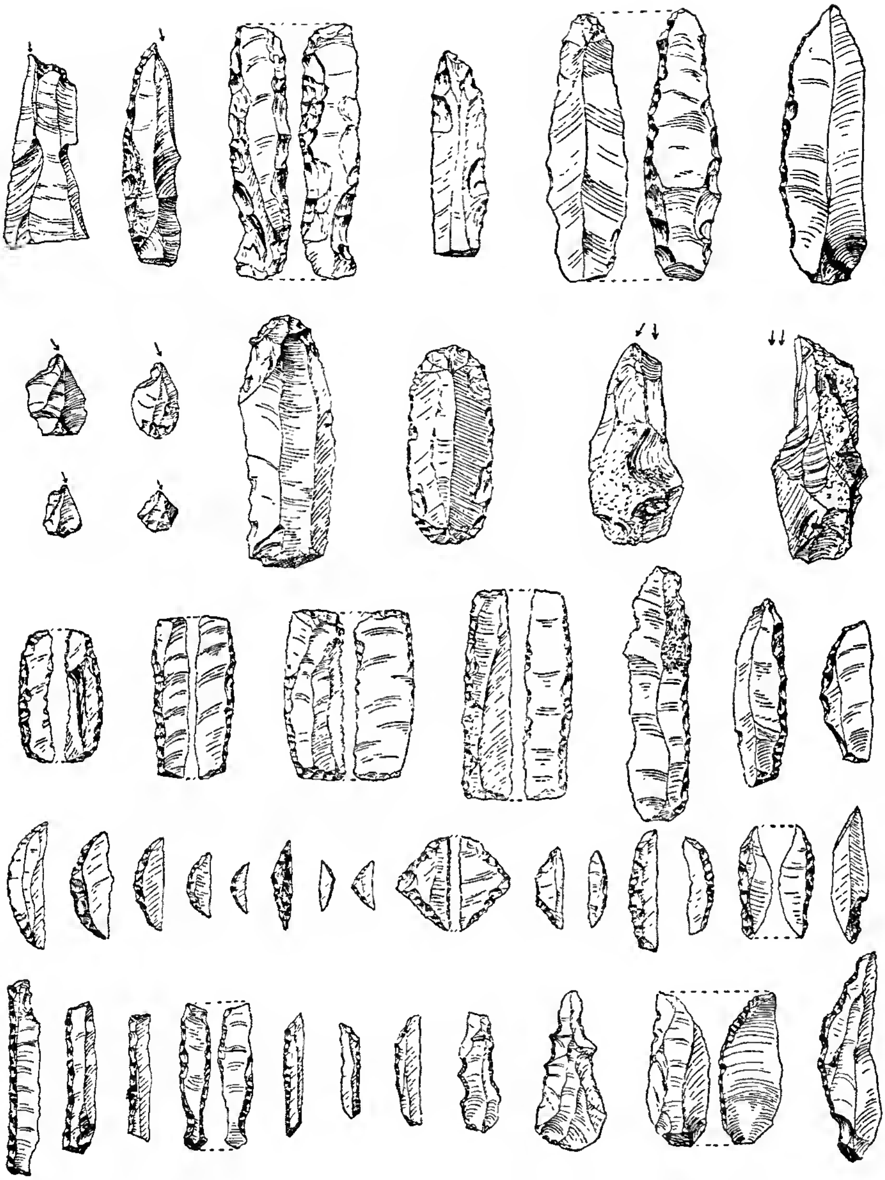

PLATE XVI. Lower Natufian implements from Layer *B2* of M. el-Wad.

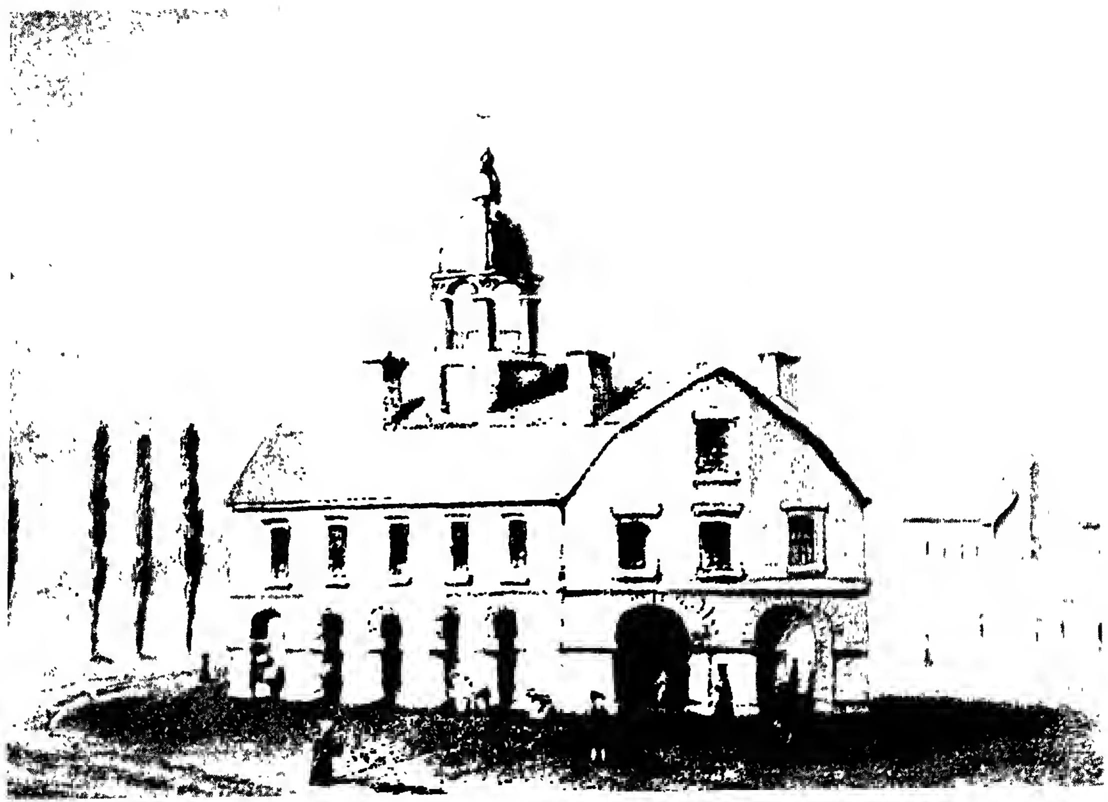

PLATE I

The Exchange, New York

Drawing in Emmet Collection in New York Public Library. Unsigned and undated; possibly made after demolition of building

THE FIRST HOMES OF THE SUPREME COURT OF THE UNITED STATES*

ROBERT P. REEDER

ABSTRACT

The Supreme Court of the United States has recently moved into the only building which was ever erected primarily for its use. The event has called for this study of its first homes. Accepted accounts of the buildings and rooms which it used are at times incorrect and even when correct are inadequate. This paper describes its homes in New York and Philadelphia quite fully and narrates their history at length. References are also made to the room occupied by the Court when it first moved to Washington and to the building occupied by it after the burning of the Capitol. It is shown that generally accepted statements as to its homes in Washington are incorrect.

In preparing this paper it has been necessary to rewrite the history of the buildings upon Independence Square, Philadelphia, from which the provincial and state governments were so long conducted, in which Congress sat during the Revolutionary War, where the Constitution of the United States was written and where the Federal Government was centered from December, 1790, to December, 1800.

INTRODUCTION

WRITERS upon the history of the Supreme Court of the United States have said but little concerning its courtrooms. Its decisions have properly engrossed their attention. But now as the Court passes into the structure which will be devoted to its uses for centuries to come we may well look back for a short while into earlier times and make note of the buildings and the rooms in which the first sessions of the Court were held.

This study is devoted to the homes of the Supreme Court in New York and Philadelphia. Upon them the secondary authorities are hopelessly misleading and the records of the seventeen nineties do not sufficiently describe the buildings or their courtrooms. To secure adequate accounts of the places in which we are most interested it has been necessary to make an extensive search of primary authorities and to piece together the records of many years. The facts which

* This paper was written mainly in the Library of Congress. I am indebted to the staff of that institution for many courtesies. I have also received help from the staffs of the Historical Society of Pennsylvania, the New York Historical Society, the Library Company of Philadelphia, the American Philosophical Society and the University of Pennsylvania.

were thus found concerning the Pennsylvania State House—the most important building in eighteenth century America—have been noted rather fully, although the Court sat there for only one term in 1791 and for only one day in 1796; and it is hoped that the other buildings in New York and Philadelphia which were occupied by the Court have been discussed sufficiently. But the necessary research has required such efforts that a similar study of the homes of the Court in the present capital of the nation could not be undertaken.

An examination of the accepted accounts of its courtrooms within the city of Washington would show that some of them are incorrect. For example, while the Court at first unquestionably sat in that part of the Capitol which is immediately north of the rotunda, for that was the only part of the building which had been erected, it did not sit on the eastern side of the building either in the room on the ground floor which it afterwards occupied for a generation or in the room on the upper floor which was later occupied by the marshal of the Court, but, according to the men who were then architects of the Capitol, its courtroom from the day on which John Marshall took the oath of office as Chief Justice until 1807 was on the western side of the ground floor.[1] And the statement that after the burning of the Capitol the Court sat for some time in the house of its clerk, Elias Boudinot Caldwell, on Pennsylvania Avenue Southeast, while it is supported by an assertion made by his granddaughter nearly eighty years later,[2] is not consistent with the fact that the United States at that time rented a house from Daniel

[1] Congress authorized the use of one of the committee rooms on the first floor of the Capitol (Sen. Jour., Jan. 21, 1801, p. 116; House Jour., Jan. 23, p. 771.) At that time the first floor was the ground floor. (*National Intelligencer*, Aug. 26, 1847, p. 3, col. 5.) In the Fine Arts Division of the Library of Congress is a ground plan of the Capitol which was given to B. H. Latrobe, the new architect of the building, in May, 1803. According to pencilled notations on that plan the Court was using a room on the western side of the ground floor. Latrobe wrote letters to President Jefferson on Aug. 31, 1805, and on Sept. 2, 1807, in each of which he furnished sketches which showed that the courtroom was so located. See also a letter by Latrobe to President Madison on Sept. 6, 1809. Latrobe, Correspondence Relating to the Capitol at Washington, Manuscript Division of Library of Congress.

[2] *American Monthly Magazine*, III, 166; *Records of Columbia Historical Society*, XXIV, 209, 211.

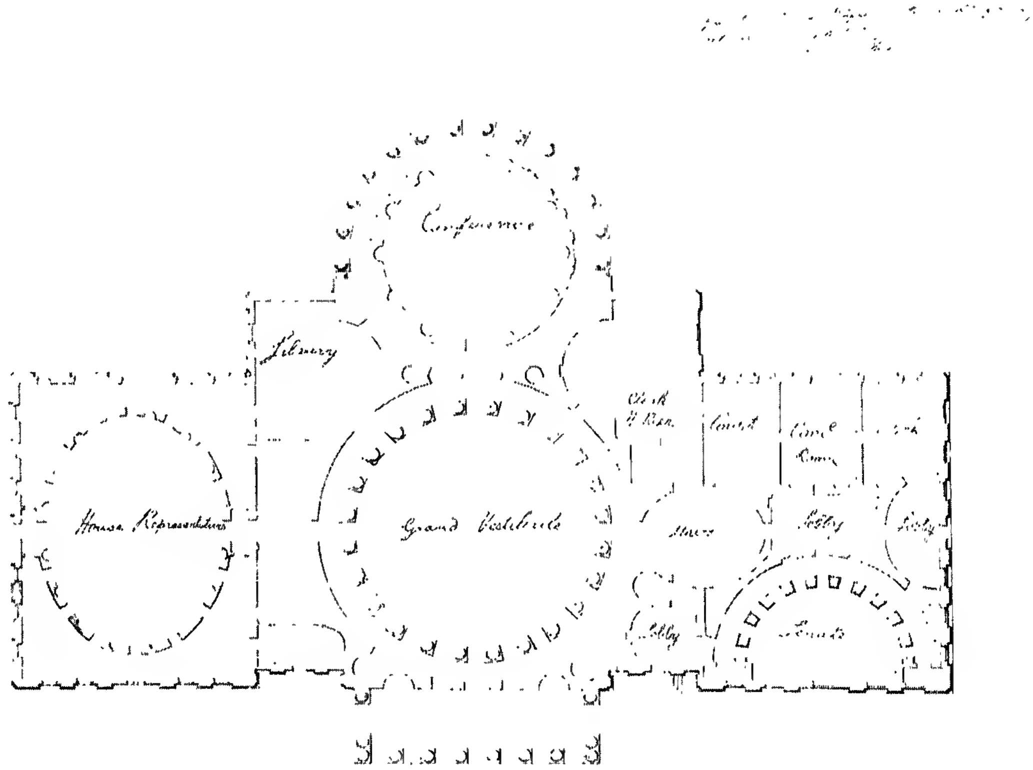

PLATE 2

PLAN FOR CAPITOL, WASHINGTON

The room on the western side of the building which was third from the north was the courtroom. Authorities cited in note 1 confirm the identification made by the penciling on this plan.

Carroll "for the use of the Supreme Court of the United States and the Circuit Court of the District of Columbia."[3] Carroll owned property on New Jersey Avenue near B Street Southeast[4] and that seems to have been the house which was rented.[5] But we shall not consider the wanderings of the Court within the city of Washington.

The Exchange, New York

The first sessions of the Court were in the City of New York. For the February and August terms of 1790 it met in the hall of the Exchange,[6] a room which had been used by

[3] At the General Accounting Office in Treasury Account 33792 of Washington Boyd, United States marshal for the District of Columbia, is a receipt given to him by Daniel Carroll on Jan. 2, 1816, for $650 for "thirteen months house rent ending the 31st of Dec., 1815, for the use of the Supreme Court of the United States and Circuit Court of the District of Columbia for the County of Washington at six hundred dollars per annum." On the home of the Court at this time I am indebted to a paper on Elias Boudinot Caldwell by D. C. Mearns and V. W. Clapp.

[4] See *National Intelligencer*, Nov. 7, 1810, p. 3, col. 5, with the same paper for Sept. 21, 1810, p. 3, col. 5.

[5] The Supreme Court sat on Capitol Hill. (*National Intelligencer*, Feb. 3, 1815, p. 3, col. 5.) On Dec. 15, 1816, Senator Jeremiah Mason wrote to Senator Rufus King that "Bailey, a reformed gambler from Virginia, has taken and fitted up for a tavern the house south of the Old Capitol, where the Supreme Court held their session last winter, together with the house adjoining." (Hillard, *Memoir and Correspondence of Jeremiah Mason*, 145.) Congress was then occupying temporary quarters elsewhere, so that the Old Capitol was the present Capitol before enlargement. The location of the house used by the courts in 1815 and used for a tavern afterwards is shown by an advertisement in the *National Intelligencer* for Nov. 12, 1816, p. 3, col. 5, with the street misnamed but with the building described as "within about 150 yards south of the Capitol and between two or three hundred yards distant from the building in which Congress meet this session; likewise near the courtroom, clerk's offices, &c."—The courtroom in 1815 was uncomfortable and unfit for the purposes for which it was used. (*Life, Letters and Journals of George Ticknor*, I, 38.)

[6] The building was constructed and owned by the city of New York. The Minutes of the Common Council of that city from 1752 to 1799 often refer to the building but under no other name than "the Exchange." State legislation so refers to it. (Laws 1784, c. 30) Notices of meetings to be held there give it that name. (Notes 30, 34.) It is so called on plans of the city. (Stokes, *Iconography of Manhattan Island*, I, pls. 34, 40, 41, 42; III, A pl. 5; see also I, pls. 25, 33.) Newspaper reports of the November, 1789, session of the District Court and of the 1790 sessions of the Supreme Court speak of the building as "the Exchange." (*New York Packet*, Nov. 5, 1789; *Daily Advertiser*, New York, Feb. 2, 1790; *Gazette of the United States*, Feb. 3, Aug. 4, 1790; *Federal Gazette*, Feb. 6; *Pennsylvania Packet*, Aug. 9; *Pennsylvania Gazette*, Aug. 11. See also *Works of John Adams*, II, 354; Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 93.) It has been sometimes referred to as "the Royal Exchange." It was so called in February, 1754, when a company of actors from London advertised that tickets to their performances might be bought at the Royal Exchange; but on the same day in the same papers tenants of the building it-

the Federal Court of Appeals—the only permanent court established by the Continental Congress—in November, 1786,[7] and by the Federal District Court in November, 1789.[8]

The building was in the middle of Broad Street at the intersection of Water Street, north of and extending half way across the latter thoroughfare.[9] It was the successor of an open, shedlike, one-story Exchange which had been at the river's edge,[10] and it was located on approximately the same site as its predecessor. Since its construction, however, the shoreline of the city has been moved forward on both rivers,[11] possibly in order to allow the docking of vessels of larger draught, so that this site is no longer at the foot of Broad Street. The Exchange measured thirty by seventy-five feet [12] and was built of brick,[13] with a ground floor which was a mere arcade,[14] open on all sides, while the second floor contained a room sixty feet long,[15] with a vaulted ceiling, starting

self were advertising their coffee-room as being in "the New Exchange." (*New York Gazette* and *New York Mercury* for Sept. 17, 24, 1753; Feb. 18, 1754; see also April 29, 1754.) The view shown in Plate I appears in J. B. Bishop, *A Chronicle of One Hundred and Fifty Years*, facing p. 42, entitled "The Royal Exchange." No such title is on the original. Some one has inscribed on the original "Merchants Exchange & Market—foot of Broad," a designation which apparently has no other authority. Regardless of other names, it is, to say the least, not probable that this public building was called "the Royal Exchange" after the Revolution.

[7] Note 35. On this court see Journals of Continental Congress for resolutions of Jan. 15 and May 24, 1780; July 1, 1785, and Feb. 9, June 27 and July 24, 1786; Jameson, "The Old Federal Court of Appeal," Papers of American Historical Association, III, 383. Some cases were argued in Philadelphia: *Pennsylvania Packet*, May 23, 1780. When Philadelphia lawyers appeared in cases reported in 2 Dallas the arguments were probably made in that city.

[8] Note 42.

[9] See Stokes, *Iconography of Manhattan Island*, I, pl. 34, for plan made in 1755; I, pl. 42, and see I, pl. 41, for plan made in 1766–67 and published in 1776; III, A pl. 5, for plan made by city surveyor in 1772, where building is placed correctly but streets are misnamed; I, pl. 40, for plan of 1775; I, pl. 64, for plan of 1797.

[10] The location is shown in Stokes, I, pls. 26, 27; see also pl. 32. The building is depicted in I, pls. 25, 33, but in the key to this view another building is incorrectly identified as the Exchange. Construction was authorized in 1691: Minutes of Common Council of New York, 1675–1776, I, 231, 265. It is called the market house in Minutes, III, 63.

[11] See plan published in 1797, in Stokes, I, pl. 64; Landmark Map, Stokes, III, pl. 174; note 39, infra.

[12] Stokes, III, A pl. 5.

[13] Minutes of Common Council, 1675–1776, V, 432, 434, 437

[14] There were five arches on each side, with two at each end. Minutes, 1675–1776, V, 380.

[15] Advertisement in *Daily Advertiser*, New York, Nov. 6, 1793.

fourteen feet from the floor and arching up under a gambrel roof [16] to a height of twenty feet.[17] The building was surmounted by a cupola [18] and a bell.[19]

Such a structure—located in the market-place, with a ground floor which was a mere arcade and a second floor which contained a large hall—was not unique. For several centuries such market-halls had been civic centres in England and on the Continent and they were well known in eighteenth century America.[20] Philadelphia had a similar building in the Court House which occupied the middle of Market Street on the west side of Second Street for a century and a quarter.[21]

[16] Minutes, 1675–1776, V, 408.

[17] Advertisement in *Daily Advertiser*, Nov 6, 1793.

[18] Minutes, 1675–1776, V, 408.

[19] Minutes, 1675–1776, VII, 155; 1784–1831, I, 531.

[20] On American public buildings see *Journals of Manasseh Cutler*, I, 262; Cloquet, *Recollections of Lafayette*, I, 178, 179; *Pageant of America*, XIII, 76, 77. For examples of similar buildings in England and on the Continent see Encyclopædia Britannica, 14th ed., X, 567; VIII, facing 478; Fletcher, *A History of Architecture*, 432, 473; Oliver, *Old Houses and Village Buildings in East Anglia*, pl. X; Guadet, *Éléments et théorie de l'architecture*, III, 20, 21; Dawber, *Old Cottages, etc., in the Cotswold District*, 67, pl. XI; Sturgis, *Dictionary of Architecture and Building*, II, 834.

[21] This structure was a Philadelphia landmark from 1710 to 1837. Despite earlier talk of building a court house or town hall and of building a new market house, the construction of the market house was definitely ordered in May, 1710, and this structure served as a court-house. (Minutes of Prov. Coun. of Pa., I, 88; II, 406–410, 447; Gabriel Thomas, *An Historical and Geographical Account of Pennsylvania*, 37; Minutes of Com. Coun. of Phila., 1704–1776, 52, 58, 69, 73, 75, 136, 137, 145, 159.) It was torn down in 1837 (Watson, *Annals of Philadelphia*, 1843 ed., I, 354.) The building was a market-hall, with a ground floor which was an open arcade, paved with brick, and the archways "secured with posts to keep out carts, horses, etc." (Minutes of Com. Coun. 137, 145; see also 159.) Stalls were rented. (Minutes of Com. Coun. 69, 74, 136, 149, 283, 475; Votes of Assembly of Pa., II, 160, 309.) The upper portion of the building was, however, put to such uses that the structure was called the Court House (*e g.*, *Pennsylvania Packet*, Aug. 11, Sept. 10, 1778; *Diary of Jacob Hiltzheimer*, 85, 86, 94, 102). It was long the civic centre of the city. Here in the early eighteenth century the Assembly held some of its sessions (*e g.*, 1712: Votes, II, 122) and here in other years the Governor received the Assembly. (Votes, II, 327, 330, 334, 370, 376, 457.) From the top of its steps important proclamations were made. (Votes, V, 239; Pa. Col. Rec., XIII, 737; XIV, 251; *Pennsylvania Packet*, Dec. 5, 1778; Nov. 13, 1779; Nov. 18, 1780; Schoepf, *Travels in the Confederation*, I, 59. See also Minutes of Com. Coun. 669, 696; *Diary of Jacob Hiltzheimer*, 52, 55, 163; *Pennsylvania Gazette*, Jan. 27, July 28, 1763; March 12, 1777; Dec. 19, 1787; *Franklin's Writings* (Smyth ed.), I, 358; Pa. Col. Rec., II, 530; III, 13; V, 82; VI, 144, 145; XI, 174, 632; XIII, 415; XV, 584.) Elections were held here. (Votes, III, 566, 586.) In maps, such as the one published in the *Gentleman's Magazine* for August, 1753, distances to points outside the city were measured from the Court House; and they were so measured in "An Account of Distances from the City of Philadelphia," a 15-page pamphlet pub-

and Faneuil Hall, in Dock Square, Boston, was just such a market-hall until rebuilt in 1805.[22]

The city of New York undertook the construction of this building in the summer of 1752 [23] and completed it in a year and a half [24] at a cost of about fourteen hundred pounds.[25] The ground floor in later times, and possibly from the beginning, served as a market-place.[26] Space upstairs was leased to tenants who maintained a coffee-room there for a number of years,[27] but it was also used for the sale of imported goods,[28] and for exhibitions [29] and meetings.[30] In 1769 it was leased

lished by William Bradford in 1755. See also Stephens, Directory, 1796, appendix, p. 69. For views of the building see Heap's East Prospect of Philadelphia, 1753 in Jefferys, *Topography of North America*, 1768; Birch, *Views of Philadelphia*, Second Street North from Market Street; Watson, *Annals of Philadelphia*, 1843 ed., I, 350. On cupola and bell see also note 106; Minutes of Com. Coun. 170. The Historical Society of Pennsylvania possesses some crude cartoons which were made while the building was in its prime and some better pictures, consistent with the cartoons and with Heap's and Birch's views, which were made after the building had been demolished.

22 The ground floor of Faneuil Hall was an open arcade. The building was in its inception a market-place, but its donor, far exceeding his first proposal, superadded a town-hall and other rooms. Permission to erect it was given in July, 1740; it was finished in September, 1742; it suffered a destructive fire in 1761 and was repaired by order of the town in 1763. A description of the building was given in the *Boston News-Letter* for January 15, 1761. The present structure dates from 1805. For accounts of the erection of the building see Boston Town Records, 1729–1742, 259, 260, 306–309; 1758–1769, 54, 59, 170; Records of Boston Selectmen, 1736–1742, 246, 252, 268, 356; 1754–1763, 133, 134, 151, 172; *Boston Weekly News-Letter*, Sept. 16, 1742; March 24, 1763; *Boston Gazette* and *Boston Post-Boy*, March 21, 1763. For a view of Faneuil Hall showing the arcade see *Massachusetts Magazine* for March, 1789.

23 Minutes, 1675–1776, V, 367, 375.

24 Minutes, 1675–1776, V, 435, 437.

25 Minutes, 1675–1776, V, 367–456.

26 Minutes, 1784–1831, I, 24, 410, 518, 525; Duer, *Reminiscences of an Old New Yorker*, 8, 9; Duer, *New York as It Was during the Latter Part of the Last Century*, 36; note 37.

27 Advertisements of Keen and Lightfoot in *New York Mercury* and in *New York Gazette* for Feb. 4, 1754, and of Lightfoot in *New York Mercury* for March 8, 1756; Minutes, 1675–1776, VI, 78.

28 Advertisement in *New York Mercury* for July 10, 1758.

29 See advertisements in *New York Mercury* for Feb. 16 to March 23, 1756, and in *New York Gazette* for March 8 and 15, 1756, of the exhibition of "an elaborate and celebrated piece of mechanism" which "plays with great exactness several fine pieces of music and exhibits, by an amazing variety of moving figures, scenes diversified with natural beauties, operations of art, of human employments and diversions, all passing as in real life." The advertisements described several elaborate scenes.

30 Advertisements in *New York Mercury* and in *New York Gazette* for April 29, 1754; advertisement in *New York Journal* for Jan. 10, 1771; account of entertainment to governor in *Rivington's New York Gazetteer* for March 24, 1774; Minutes, 1784–1831, I, 54, 314, 505, 545, 592; advertisement in *Daily Advertiser*, New York, Feb. 6, 11, 12,

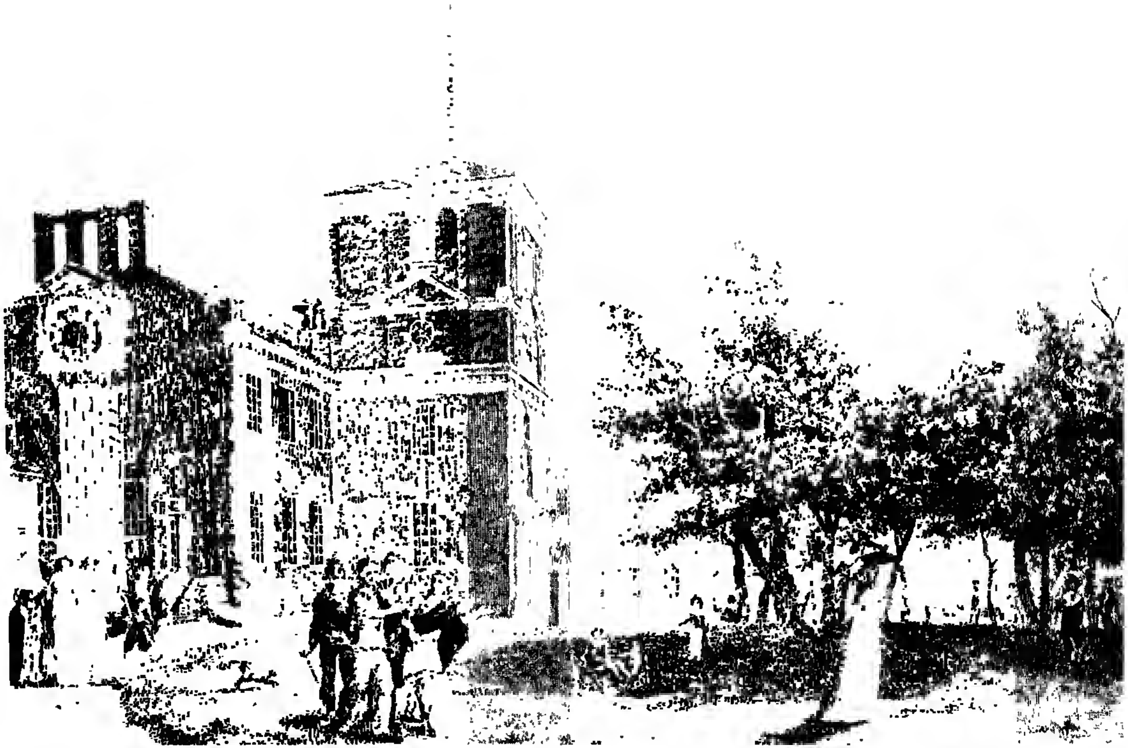

PLATE 3

BACK OF THE STATE HOUSE, PHILADELPHIA

From Birch, "Views of Philadelphia." The courtroom was on the ground floor, extending across the end of the building to the left of the tower.

to the chamber of commerce upon the conditions that it should be put into good repair and that the city corporation should be permitted to make use of the building as often as it should judge necessary.[31] From September, 1771, elections for city offices were held in the Exchange.[32] A coffee-room was again opened in December, 1778.[33] The state legislature met in the building [34] and the Federal Court of Appeals sat there in November, 1786.[35]

Further use of the Exchange was provided for by the City Fathers. In October, 1788, they spent over two hundred pounds in repairing the room "for the accommodation of the courts of justice and meetings of the corporation of this city."[36] In the same month they received a petition from citizens who were apprehensive that the markets then held under that building might at certain seasons of the year be offensive to those who were to use the hall, asking permission to build a market one hundred and thirty-three feet long and twenty feet wide on a site between the Exchange and the river, then occupied by oystermen and others, which was known as the Long Bridge.[37] The permission was promptly granted,[38] so

13, 15, 1790; notes 34, 35, 43. John Adams, on his way to the Continental Congress, wrote on August 25, 1774 (*Works*, II, 354), "We afterwards dined in the Exchange Chamber, at the invitation of the Committee of Correspondence, with more than fifty gentlemen, at the most splendid dinner I ever saw."

[31] Minutes, 1675–1776, VII, 149. See also Laws of N. Y., 1784, c. 30. The upper part of the Exchange had been previously leased by the year at rentals ranging from thirty to eighty pounds per year. Minutes, 1675–1776, V, 435; VI, 3, 47, 78, 124, 365, 409.

[32] Minutes, 1675–1776, VII, 314, 374, 444; VIII, 53, 104; 1784–1831, I, 76, 168, 247, 318, 398, 484, 592, 670.

[33] *Royal Gazette*, Dec. 2, 1778.

[34] See, for example, proclamation of Governor Clinton in *Daily Advertiser*, New York, Nov. 18, 1785; Minutes, 1784–1831, I, 508; Duer, *New York as It Was During the Latter Part of the Last Century*, 36; note 43.

[35] *Daily Advertiser*, New York, Nov. 13 and 14, 1786, published this notice: "The Court of Appeals have met agreeable to the Resolve of Congress, and are now sitting in this city, in the room over the Exchange, of which all persons concerned are desired to take notice. New York, Nov 13, 1786."

[36] Minutes, 1784–1831, I, 399, 407, 409, 418, 492. On Jan. 29, 1790, eleven pounds were paid for "repairs to the court room in the Exchange": p. 520.

[37] Manuscript petition quoted in Stokes, *Iconography of Manhattan Island*, V, 1232. The Long Bridge was originally a pier which extended Broad Street into the river (Stokes, I, pl. 25, 33, 34; III, A pl. 5) but after 1772 and before 1797 the harbor on both sides of this pier was filled in with solid ground: note 39.

[38] Minutes, 1784–1831, I, 409, 410.

that by June, 1789, a new market had been erected over the spot where the "bridge" had lately stood.[39] The Common Council thereupon appointed a committee to direct the removal of the butchers and others from the Exchange and to regulate the stands in the new market.[40] Finally, in October, 1789, chains were provided "to fix across the streets at the Exchange to prevent the courts of justice and the Legislature when they meet from interruption from the noise of carts." [41]

On November 3, 1789, "the Federal Court for the district of New York, met at the Exchange." [42] The House of Assembly of the State sat in that room from January to April, 1790, holding morning sessions,[43] and on February first of that year it became the first court-room of the Supreme Court of the United States.

The Supreme Court held afternoon sessions [44] in the room until the tenth of the month, when it adjourned "till the time appointed by law for holding another session," [45] and it sat there again in the following August.[46] No cases were on the docket of the Court during those two terms, so that the selection of officers of the Court, the entering of orders describing the seals to be used by the Supreme and the Circuit Courts, the framing of rules and the admission of members to its bar constituted the only matters which came before it.

[39] Minutes, 1784–1831, I, 461, 507. The granting of water lots by Common Council in 1772 (Minutes, 1675–1776, VII, 361) seems to indicate filling-in about the end of Broad Street around that time. A survey of those lots on Nov. 10, 1772, appears in Stokes, III, A pl. 5, where streets are misnamed. The plan published in 1797 (Stokes, I, pl. 64) shows that the shore line had been extended. See also plan of 1799, published in 1803 (Stokes, I, pl. 70); it shows the new Exchange Market; the old Exchange had been demolished.

[40] Minutes, 1784–1831, I, 468.

[41] Minutes, 1784–1831, I, 498. See also 506.

[42] *New York Packet*, Nov. 5, 1789. See also *Federal Gazette*, Nov. 7.

[43] Minutes, 1784–1831, I, 508; New York Assembly Journal, Jan.–April, 1790. In *Federal Gazette* for Feb. 4, 1790, the room in which the Supreme Court sat was called the Assembly-Chamber.

[44] Minutes of the Supreme Court.

[45] *Daily Advertiser*, New York, Feb. 2, 3, 4, 10, 11, 1790; *New York Journal*, Feb. 4, 11; *Gazette of the United States*, Feb. 3. 6; *Federal Gazette*, Feb. 4, 6, 8, 10, 13; *Pennsylvania Gazette*, Feb. 10; *Pennsylvania Packet*, Feb. 6, 9, 11, 16. The accounts were short but they doubtless told all of the little that was done. The *Packet* for Feb. 11 and 16 summarize the proceedings of the term quite fully.

[46] *Gazette of the United States*, Aug. 4, 1790; *Pennsylvania Packet*, Aug. 9; *Pennsylvania Gazette*, Aug. 11.

In May, 1790, the Law Society was granted permission to use the courtroom in the Exchange;[47] in September of the same year "a petition from the Society of St. Tammany for the use of the room in the Exchange was read and the prayer thereof granted, except when the room shall be wanted for public use";[48] and soon afterwards a museum, of which elaborate accounts have been preserved, was established there by one of the officers of the Tammany Society.[49] This museum contributed to the education and entertainment of the people of New York for several years. But the building doubtless interfered with the growing traffic of the city. After repeated petitions for its removal had been received,[50] the Common Council ordered its removal in March, 1799.[51]

The Pennsylvania State House

The second home of the Court was in Philadelphia, the seat of government of the United States from December, 1790, to December, 1800.[52] For the term of February, 1791, in which the Court met only two days,[53] the sessions were held in the building which was then called the State House but which has been also known to later times as Independence Hall.[54]

[47] Minutes, 1784–1831, I, 543.

[48] Minutes, 1784–1831, I, 592.

[49] See advertisements in *Daily Advertiser*, New York, Nov. 6, 1793; Aug. 24, 1798; Duer, *Reminiscences of an Old New Yorker*, 8; Duer, *New York as It Was During the Latter Part of the Last Century*, 35; *Dunlap's American Daily Advertiser*, May 30, 1791. The advertisement in 1793 told of many mounted animals and said that "The room in which the museum is contained is 60 feet by 30 with an arch of 20 feet high, on which is elegantly painted a sky blue, and intermixed with various kinds of clouds in some of which are naturally represented thunder storms, with flashes of lightning." On the walls were painted a large number of trees, birds and animals. "Tickets . . . may be had in the front room up stairs opposite the door of the museum." On a menagerie established on nearby city property by the owner of the museum see Minutes, 1784–1831, II, 70, 248, 250, 401. Compare notes 141, 142, 260, 261, 266.

[50] Minutes, 1784–1831, I, 721, 736; II, 455, 521.

[51] Minutes, 1784–1831, II, 523.

[52] Act of July 16, 1790.

[53] Minutes of the Supreme Court.

[54] In the eighteen twenties the room in which independence had been declared was called Independence Hall. (*Poulson's American Daily Advertiser*, Dec. 6, 1828; Childs, *Views of Philadelphia*, and Wild, *Panorama of Philadelphia*, texts to views of State House.) The building itself was long afterwards known as the State House.

The minutes of the Supreme Court do not tell us just where it sat, nor do the newspapers of the day, and of all the justices and lawyers who were present apparently only one man has left a record of its meeting-place. That man, however, was Edward Burd, the prothonotary of the Supreme Court of Pennsylvania. The candidates for admission to the bar of the federal court from that State called upon him to certify that they had been admitted to practice in the court of which he was prothonotary;[55] he himself was admitted to the bar of the Supreme Court of the United States at that time;[56] and on the second day on which the new court was in session he wrote a description of its proceedings. His account started with the statement that "The Supreme Court of the United States opened on Monday the 7th inst. in which Chief Justice Jay and Justices Cushing, Wilson and Iredell sat. A number of the gentlemen of the bar of this city attended at their lodgings and escorted them to the State House. The Court opened but there was no business done" other than the consideration of applications for admission to the bar, concerning which there was a prolonged discussion which Burd recounted at length.[57] In view of his clear-cut statement there can be no doubt that the sessions of the Supreme Court for February, 1791, were held in the Pennsylvania State House.

Moreover, while the City Hall, at Fifth and Chestnut Streets, is usually referred to as supplying the second courtroom of the highest court of the land, there is an abundance of reason for believing that that building was not ready for occupancy in February, 1791,[58] and, on the other hand, the State House undoubtedly contained a suitable courtroom, for the justices of the Supreme Court of the State had held a court of oyer and terminer there as recently as January 24th,[59] a special circuit court of the United States to hold a jury trial in that building was announced for February 21st,[60] and the

[55] Burd Papers, 168.
[56] Minutes of the Supreme Court.
[57] Burd Papers, 168.
[58] Note 200.
[59] *Freeman's Journal*, Jan. 19, 1791.
[60] *Federal Gazette*, Feb. 12, 1791.

Supreme Court of the United States sat there in August, 1796.[61] The room which had served as a courtroom for the highest court of Pennsylvania for more than forty years was still used as a courtroom and had not been taken over for use by one branch of the legislature, as has been said repeatedly,[62] without any justification for the statement.[63]

The building in which the Court sat was the best known structure in America. For nearly sixty years it had been the home of the Pennsylvania legislature and, for a large portion of that time, of the highest court of the Province and Commonwealth.[64] From 1775 to 1783 Congress had held most of its sessions in this building.[65] In it independence had been

[61] Minutes of the Court for Aug. 5, 1796. On the ten other days of that term it sat in the City Hall.

[62] Etting, *History of Independence Hall*, 120; Scharf and Westcott, *History of Philadelphia*, III, 1788.

[63] On the continued use of the courtroom, see note 64; on the Assembly-rooms, see note 140.

[64] Use of the building for the Supreme Court was planned when the building was erected. (Votes of Assembly of Province, III, 175, 208; notes 95, 103; see also Votes, III, 522, 541; VI, 551.) The court sat here many years (*Gentleman's Magazine*, Aug., 1753; Burnaby, *Travels in North America*, 1st ed., 44, 3d ed., 59; Duché, *Observations*, 10; essay written in 1774 in 23 Pa. Mag. Hist. and Biog., 418; Jour. of House of Rep. of Com., I, 482; Pa. Col. Rec., XI, 534; *Pennsylvania Packet*, March 14, 1780; Schoepf, *Travels in the Confederation*, I, 69; Minutes of General Assembly, Jan. 21, March 1, 8, 1784; Nov. 23, 30, 1786; Pa. Col. Rec., XV, 337; note 148; *Columbian Magazine*, July, 1787; Pa. Archives, XI, 559; *Pennsylvania Gazette*, Sept. 17, 1788; March 18, 1789; House Jour., March 8, 15, 19, 23, April 4, 1793; Sen. Jour., March 5, 1795) and its justices in circuit here held courts of oyer and terminer at times which they appointed and the sheriff proclaimed. (Acts of May 22, 1722; May 20, 1767; Jan. 28, 1777; *Pennsylvania Gazette*, Sept. 20, 1775; April 3, 1776; *Pennsylvania Packet*, Dec. 18, 1779; Sept. 19, Oct. 24, 1780; *Pennsylvania Journal*, July 4, 1781; *Independent Gazetteer*, April 2, May 21, June 25, July 2, 1785; *Diary of Jacob Hiltzheimer*, 77; *Journals of Manasseh Cutler*, I, 262; *Pennsylvania Gazette*, April 4, 1787; July 2, 1788; *Freeman's Journal*, Jan. 14, July 15, 1789; April 7, 1790; Jan. 12, 1791; Jan. 4, 1792; *Federal Gazette*, Jan. 19, Sept. 13, 1790; Jan. 10, 1792; Stephens, Philadelphia Directory, 1796, appendix, p. 68.)—When in 1802 Peale was granted the use of most of the State House for his museum (note 141), the room on the western side of the first floor was not included.—The Federal Court of Appeals held some of its sessions in this building: *Pennsylvania Packet*, May 23, 1780.

[65] Washington, *Diaries*, II. 196; Burnett, Letters of Members of Continental Congress, I, 126, 133, 211; III, 321, 329, 333, 340, 363; VII, 193, 197, 199, 203, 220, 222; Minutes of General Assembly, Sept. 3, 1783; *Pennsylvania Packet*, July 4, Aug. 11, 1778; Journals of Contiental Congress, VII, 168; XI, 662, 671; XXV, 973; Jour. of House of Rep. of Com, I, 227. Its accommodations were rent-free. (Burnett, I, 276; Minutes of Sup. Ex. Coun. of Pa., XI, 706.) On meeting in Carpenter's Hall in Sept.-Oct., 1774, see Burnett, I, 4, 8-11.

declared and the Constitution of the United States had been written.[66] The state constitution of 1776 had been framed and adopted within its walls.[67] The council of censors, considering the operation of that constitution, had met here, with several recesses, from November, 1783, to September, 1784.[68] Here had met the state convention which ratified the Federal Constitution [69] and the convention which framed and adopted the state constitution of 1790.[70] It was the chief building of a group of structures, erected as parts of a common scheme, in which the legislative and judicial activities of both Nation and State were to be conducted for the next decade. The Pennsylvania legislature remained in the State House for another nine years; [71] Congress was quartered in a new building only a few feet to the west of it [72] and only a few feet to the east of the State House the city of Philadelphia was then erecting a City Hall which was to furnish accommodations to the Supreme Court of the United States for nine years.

During the first third of the eighteenth century the small House of Representatives which constituted the one-chamber legislature of the Province had no permanent home of its own, but met sometimes in the Court House [73] which the city of Philadelphia had built in the middle of High Street (afterwards known as Market Street) [74] and more frequently in

[66] Journal of Federal Convention, May 14, 1787 (Documentary History of Constitution, I, 48; Farrand, Records of Federal Convention, I, 1); Washington, *Diaries*, III, 216, 217; Farrand, *Records*, III, 98; *Columbian Magazine*, I, 513; *Journals of Manasseh Cutler*, I, 262; *Diary of Jacob Hiltzheimer*, 131. The Articles of Confederation were framed in part in Philadelphia (Journals of Continental Congress, V, 546, 674; VII, 240, 287, 300, 328, 351; VIII, 492, 501), but received further consideration, and were submitted to the States, when Congress was sitting at York, Pa., during the British occupation of Philadelphia. (Journals, IX, 778–907; Burnett, Letters, vol. 2.)

[67] Jour. of House of Rep. of Com., I, 49, 89; *Pennsylvania Gazette*, Oct. 16, 1776.

[68] Proceedings Relative to Calling Conventions of 1776 and 1790, etc., pp. 66–128. For duties of council see constitution of 1776, II, sec. 47.

[69] Minutes of Convention of Commonwealth of Pennsylvania, 1787, p. 3; Hazard, *Register of Pennsylvania*, IV, 257; *Pennsylvania Journal*, Nov. 2, 21, 24, 1787; *Pennsylvania Packet*, Nov. 22, 1787; *Diary of Jacob Hiltzheimer*, 138.

[70] Minutes of Convention of Commonwealth of Pennsylvania, 1789, pp. 7, 211; Proceedings Relative to Calling of Conventions of 1776 and 1790, etc., pp. 137, 296

[71] Act of April 3, 1799.

[72] *Columbian Magazine*, I, 514

[73] Votes of Assembly of Province of Pennsylvania, II, 122. See also note 21.

[74] By 1742 the street was usually called Market Street: Votes, III, 565, 568, 573, 577, 580, 586, 588. But see 585; and also *Freeman's Journal*, Aug. 17, 1791, p. 3.

rooms in private dwellings which were rented by the session.[75] In February, 1729, however, after disorders in Philadelphia had caused the Assembly to consider removing to another town,[76] citizens of Philadelphia City and of Philadelphia County petitioned for the enactment of a law empowering the city and the county to build a market and state-house in High Street near the prison,[77] which was at Third Street.[78] In other words, they sought the erection of a building one block west of the Court House, to be placed like it in the middle of the street, with an open arcade at the street level within which there would be market stalls, and a hall on the floor above. The Assembly took this petition into consideration and acted three months later.

In the meanwhile another movement was under way. At that time, as all through the colonial period, there was a dearth of currency. The necessity for an increase in its amount appeared to be especially urgent, and one of those who joined in the call for an issue of paper money was a young printer named Franklin, who wrote and published an effective pamphlet on "The Nature and Necessity of a Paper Currency." [79] A law was enacted which provided for printing thirty thousand pounds in bills of credit, of which twenty-six thousand pounds were to be loaned on land security for sixteen years at five per cent interest, not more than three hundred pounds being loaned to any one person. This law appropriated two thousand pounds of the total issue towards the building of a State House, the two thousand pounds to be sunk by annually destroying, for that purpose, two hundred

[75] Minutes of Provincial Council, II, 26; Votes, II, 334; III, 62, 208. For some, and perhaps all, of the sessions from 1729 to 1735 the Assembly sat in an old house upon the State House lot adjoining the site of the State House itself. Votes, III, 208, 237. On 12 Mo. 12, 1710/11 (Votes, II, 89), in order to secure a quorum seventeen members met at the house of Thomas Masters "who, being indisposed, could not venture abroad"; and on May 14, 1764 (Votes, V, 339) Speaker Norris wrote to the clerk of the Assembly saying that during the greatest part of the past winter the members had met at his house.

[76] Votes, III, 62; Minutes of Provincial Council, III, 340.

[77] Votes, III, 72.

[78] See Acts of Feb. 26, 1773; Sept. 13, 1785, sec. 3.

[79] Smyth, *Life and Writings of Benjamin Franklin*, I, 139, 306; II, 133.

pounds of the paper money which should be received in payment of interest on the twenty-six thousand pounds thus loaned out.[50] The printing of the bills of credit was entrusted to the young man whose pamphlet had aided in securing the enactment of the law.[51]

The appropriation of two thousand pounds provided only a small portion of the amount which was ultimately spent upon buying a site and erecting a State House; but it constituted a precedent as to the manner of securing funds for the purpose. The reports of the trustees of the General Loan Office, as printed each year in the Votes of Assembly, show that during the many years in which the State House and the additions to it were under construction the necessary funds were secured almost exclusively from interest on money loaned in bills of credit.[52]

The committee in charge of the work did not undertake to build a market-hall, as had been suggested, nor did it propose to move out to the central square which Penn had long before selected as a civic centre[53] for his "green country town."[54] It bought some lots on the outskirts of the town, on the south side of Chestnut Street between Fifth and Sixth Streets, and there, after considerable delay, commenced construction.[55] The committee may have contemplated buying all of the land which finally became State House

[50] Act of May 10, 1729, c. 303, pp. 372, 387; Votes, III, 82, 89.

[51] Smyth, *Life and Writings of Benjamin Franklin*, I. 306.

[52] Down to December 31 1760, £ 12.060 were paid from the revenues of the General Loan Office towards buying ground and building the State House, its tower and its wings (Votes, III, 127, 321, 322, 344, 414, 439, 493, 531, 559; IV, 16, 45, 62, 88, 148; VI, 70–80 From the same source £ 428 were spent on bells. (Votes, VI, 71, 72; see also note 107.) In 1742 £ 303 were spent from the general revenues of the Province for work done on the State House (Votes, III, 493) and the £ 494 paid in 1759 (Votes, V, 84) for the clock which had been installed six years earlier may have come from the general revenues. On March 24, 1733 (Votes, III, 188), the Assembly authorized spending £ 400 of public money for building two offices adjoining the State House. The money may, however, have been paid by the General Loan Office: see Votes, III, 194, 321, 322. On other expenditures from interest money see note 183.

[53] Letter from William Penn to the Committee of the Free Society of Traders, 1683, map and p. 12

[54] So called in letter of instructions from William Penn to William Crispin and others, September 30, 1681, printed in Janney, *Life of William Penn*, 169.

[55] Votes, III, 175, 180, 181, 194, 228 £ 550 had been paid for the site: Votes, III, 194.

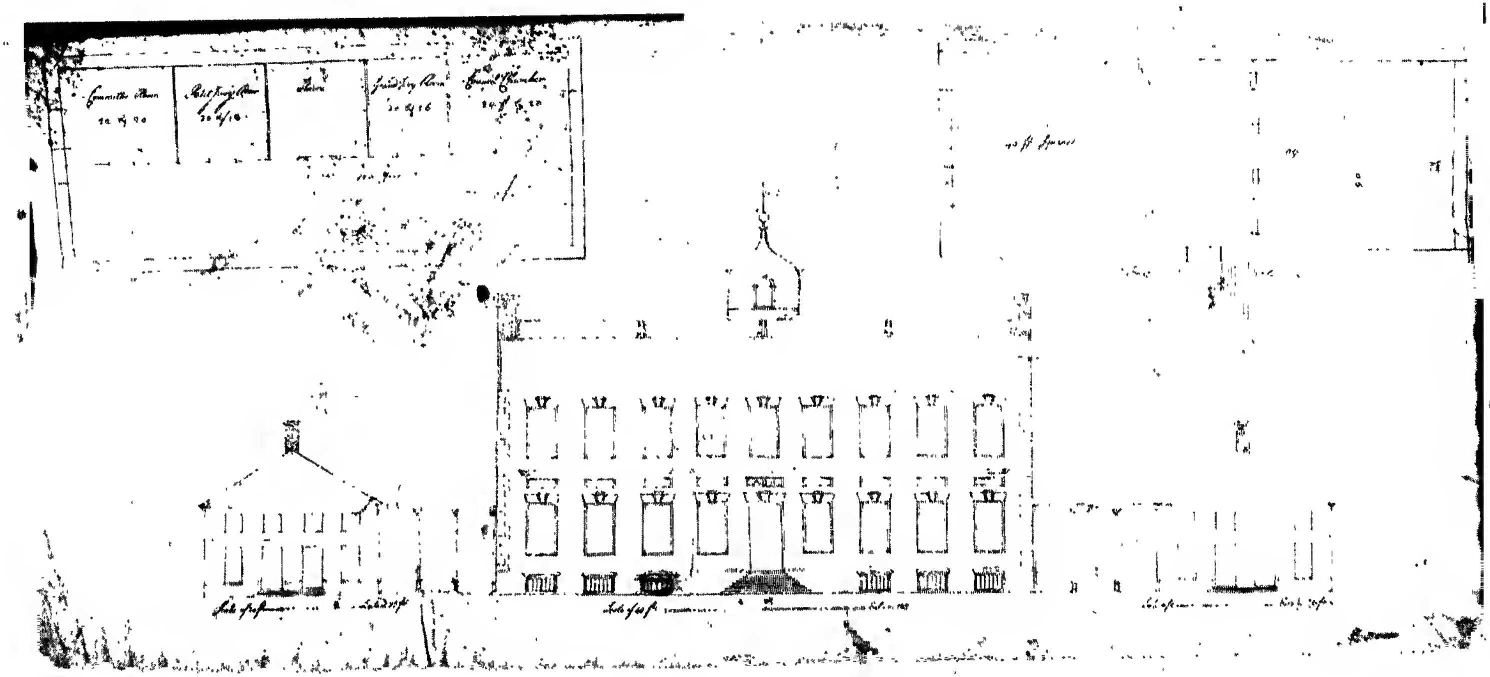

PLATE I

HAMILTON'S PLAN OF STATE HOUSE

Plan which Andrew Hamilton submitted to the General Assembly on August 11, 1732. It is in the library of the Historical Society of Pennsylvania

Square; but the Province did not secure all of the property south to Walnut Street until the seventeen sixties.[86]

In exterior appearance the State House as originally constructed was a modified composite of several private dwellings which were depicted in *A Book of Architecture*, by James Gibbs, an English book which had been published in 1728.[87] The main building, a little over one hundred feet in length, had on each side a wing about fifty feet long, connected with the main building by a brick portico.[88] There was a cupola in the middle of the roof but no tower.[89] The interior plan of the building was governed by the facts that there was only one House of Assembly, the sessions of which, if we may judge by a committee report in 1764, were usually secret,[90] and that it was desirable to provide accommodations for the Supreme Court of the Province and for the Governor's advisory council. The Assembly and the court were housed on the main floor to the east and the west of the central hallway, the Assembly-room being guarded with doors, while the court-room was reached through open archways.[91] The

[86] Act of May 14, 1762, c. 10, p. 215; Votes, V, 218, 224. Property bought under this act cost £ 4000: Votes, VI, 753. Purchase of some property fronting on Walnut Street had been authorized ten years earlier: Votes, IV, 222; see also 230, 267.

[87] See pls. 38, 39, 56, 57, 58, 63, 64.

[88] On size of main building, see note 96; on the wings, 23 Pa. Mag. Hist. and Biog. 418; on the porticos, note 115. A plan was approved by the Assembly on August 11, 1732. (Votes, III, 180.) On March 24, 1732/3 (Votes, III, 188) it was resolved that "for the greater security of the public papers of this Province (agreeable to a plan now produced before the House) two offices be built adjoining to the State House." The Historical Society of Pennsylvania possesses what is called Hamilton's plan, showing wings somewhat different from those which were built. (See Plate 4.)

[89] See note 106.

[90] See petition of Feb. 25, 1764 (Votes V, 320) and committee report on March 6, on practices in Pennsylvania and neighboring colonies (Votes, V, 324, 325) and also rules of Assembly as given in Votes, VI, 3, 550. Compare Votes, IV, 781; Constitution of 1776, c. II, sec. 13; Journals of House of Representatives of Commonwealth, I, 337.

[91] Note 95; Minutes of General Assembly, Nov 23, 30, 1786; *Journals of Manasseh Cutler*, I, 262.—On August 11, 1732, Speaker Hamilton presented to the Assembly a proposed plan of the State House which was approved by the Assembly. (Votes, III, 180.) The Historical Society of Pennsylvania has a parchment which purports to be and appears to be that plan. (See Plate 4.) In it the interior walls on the first floor are placed approximately as at present. They are in line with the windows adjacent to the north and south entrances. In order to admit light through those windows the interior walls stop a foot or two short of the outside walls. In the arcaded wall between the central hallway and the courtroom the end gaps are left open, perhaps spanned by half arches; in the wall of the Assemblyroom the gaps are closed by thin

council-room was on the second floor. The Provincial Council itself was a small body, but as the Assembly waited upon the Governor when presenting its Speaker[92] and when receiving his assent to bills,[93] it was necessary to have a room which was large enough to accommodate the Assembly on such occasions. That room was the concil-room.[94] It was in the southwestern corner of the building. In the southeastern corner was another room of the same size which was built to be a committee-room for the Assembly but which afterwards served as a place of deposit for the small arms of the city. The entire northern portion of the second floor was devoted to a "gallery," later known as the "long room."[95] The Assembly-room and the court-room were each forty feet square, with a hallway twenty feet wide between them. Their ceilings were twenty feet high. The "long room" measured one hundred by twenty feet and the two rooms to the south of it each measured forty by twenty feet.[96]

While at least a portion of the site was secured in 1729, the erection of the State House did not commence until 1732.[97] The Assembly apparently moved into the building in September, 1735,[98] although the Assembly-room was still

partitions, perhaps of wood panelling, set back to the eastern line of the interior wall to form rectangular niches in the hallway. The windows adjacent to the southern entrance disappeared with the building of the tower in 1750 (p. 560), if not earlier. At those adjacent to the northern entrance there are now closed shutters and there are no niches in the hallway. The facade was not built entirely as Hamilton had proposed, so that it is possible that those shutters have always been closed.

[92] Votes, II, 403, 457; III, 3, 95, 125, 166, 219, 444.

[93] Votes, III, 116, 211, 343, 521.

[94] Votes, V, 85, 87, 188, 203, 432; VI, 262, 340. See plan cited in note 95.

[95] See plan in Penn Manuscripts, Warrants and Surveys, folio 111, at Historical Society of Pennsylvania, and description of building, written in 1774, in 23 Pa. Mag. Hist. and Biog. 419. The Hamilton plan (Plate 4) shows four rooms on the south side of the second floor, providing also for grand and petit juries. May we not suppose that the two rooms there were sometimes used as jury rooms?

[96] *Gentleman's Magazine* for August, 1753, p. 373; Sims and Willing, *Old Philadelphia Colonial Details*, pls 17–21.

[97] Note 85.

[98] On June 24, 1735 (Votes, III, 237) the Assembly "Ordered, That the two old houses next opposite to the State House (the one being the house where the Assembly now sits) be demolished, and the materials thereof disposed of to the best advantage; and then the House adjourned to the fifteenth of September next" In September, 1736 (*Pennsylvania Gazette*, Sept. 30, 1736) William Allen, near the end of his service as mayor of Philadelphia (Minutes of Common Council of Philadelphia, 1704–1776,

unplastered and without glass in all of its windows and remained in that condition for half a dozen years.[99] One of the wings whose construction had been ordered in March, 1732/3,[100] was ready three years later for the custodians of public records to move into the offices there provided;[101] but it seemed necessary for the Assembly to adopt repeated resolutions prodding the superintendents of the State House to complete the main building.[102] Plans for the finishing of the courtroom were not submitted until November, 1743;[103] and it was December, 1750, before the prothonotary of the Supreme Court notified the Assembly that he had removed the records of the court from his house to an office in one of the wings of the State House.[104] The council chamber was first used in February, 1747/8.[105]

p. 361), "made a feast for his citizens at the State House" The report of "the most grand and the most elegant entertainment that has been made in these parts of America" does not say that it was inside the building. If inside, it may have been in the Assembly-room, for that may have been the room on which most progress had been made.

[99] On January 25, 1734/5 (Votes, III, 229) the Assembly had directed that the Assembly-room be wainscotted. On February 18, 1735/6 (Votes, III, 268) it was reported that wainscotting would cost more than could well be afforded at that time, and the Assembly thereupon resolved that good plastering would be sufficient. Glass was not put into the windows until the wall inclosing the grounds in the rear of the State House was completed lest the windows should suffer much damage by breaking. (Votes, III, 433) On June 6, 1741 (Votes, III, 434) it was resolved that the Assembly-room should be plastered, glazed and finished, all but the ceiling and upper work, by the next meeting of the Assembly; and that the ceiling and upper work should be finished as soon as a workman could be secured. Compare Votes, IV, 30.

[100] Votes, III, 188.

[101] Votes, III, 248, 260, 263, 275, 458, 465. In 1774 (23 Pa. Mag. Hist. and Biog. 418) a writer said that the eastern wing was the place of deposit of the records. This appears to show that the eastern wing was the one which was first finished and that therefore the two old houses referred to in note 98 were west of the State House. In June, 1759 (Votes, V, 59) the Assembly, taking into consideration that the State House and the public records kept therein had been exposed to great risks by fire, from the lodging of numbers of Indians, frequently coming to town, in one of the wings thereof, directed that, with the assent of the Governor, a small house suitable for lodging the Indians, be erected adjoining the wall of the State House yard. Burnaby, *Travels in North America*, 1st ed., 44, 3d ed., 59, refers to accommodations for Indians. See also 23 Pa. Mag. Hist. and Biog. 418.

[102] Votes, III, 432–434, 505, 522, 541.

[103] Votes, III, 541.

[104] Votes, IV, 156. In later years the prothonotary again kept the records in his own house: Minutes of Assembly, 1789/90, p. 119; House Jour., 1792/3, p. 343; Burd Papers, 194, 195. See end of note 172.

[105] Minutes of the Provincial Council, Pa. Col. Rec., V, 69, 193.

In January, 1749/50, the Assembly authorized the erection of "a building on the south side of the said House to contain a staircase, with a suitable place therein for hanging a bell."[106] The purchase of a bell was authorized in October, 1751. It was ordered from England and arrived about the end of the following August; was cracked early in September by a stroke of the clapper; was recast in Philadelphia six months later; was again recast in April or May and was placed in position about the first of June, 1753.[107] There was no clock in the steeple, however, until seventy-five years later.[108] A clock was ordered in March, 1752,[109] and was installed within a year or two,[110] but despite the terms of the order of the Assembly, the works of this clock were placed in the attic and

[106] Votes, IV, 135. The Hamilton plan of the State House (Plate 4) shows a cupola in the middle of the roof. Kalm, *Travels into North America*, in a statement which apparently antedates 1750, refers (I, 44) to a tower with a bell in the middle of the State House. On p. 45 he says that the Court House on Market Street has a little tower and a bell. Under all the circumstances, when Kalm says "tower" he evidently means "cupola."

[107] For authorization of purchase see Votes, IV, 203. Instructions from superintendents of the State House were given in letters of Nov. 1 and 4, 1751, sending a bill of exchange for £ 100, computed as approximately the cost of the two thousand pound bell. This cost £ 165 in Pennsylvania money: Votes, IV, 230. See Letter Book of Isaac Norris, at Historical Society of Pennsylvania, for dates named and for Sept. 1, 1752; March 10, April 14, Nov. 8, 1753. Votes, IV, 230, show approval on Aug. 22, 1752, of payment of £ 198 (Pennsylvania money) to Norris to send for a bell. The bill of Pass & Stow, who did the recasting in Philadelphia, was for £ 60-13-5. (Isaac Norris Manuscripts, Loan Office Accounts 1759–1766, p. 106; Votes, IV, 267.) Norris wrote to England on Nov. 8, 1753 (see Letter Book), that if the makers of the original bell would make a new one for the cost of recasting, the metal of the present bell would be returned at the first opportunity. On Aug. 13, 1754 (Votes, IV, 323), "The Speaker, in behalf of the superintendents of the State House desired the opinion of the House whether they should send the bell to England in part pay for the new one (as they had the right to do by their agreement) or to keep them both for public use. Resolved, That the said superintendents do pay for the new bell, and keep the old one for such uses as this House may hereafter appoint." Votes, IV, 325, 326, show on Aug. 17 a report of £ 170 paid towards a bell. This was Pennsylvania money paid for £ 100 sterling. The bell now kept as a relic is the one cast by Pass & Stow.—"Last week was raised and fix'd in the State House Steeple the new great Bell, cast here by Pass and Stow": *Pennsylvania Gazette*, June 7, 1753.

[108] Note 270.

[109] Votes, IV, 221.

[110] Votes, V, 84. On Sept. 30, 1759, the Assembly paid Mr. Stretch £ 494 for making the clock and cleaning and repairing it for six years. Forty-two years before a Peter Stretch was paid about nine pounds for work done and disbursements on the "town clock" of Philadelphia: Minutes of Common Council of Philadelphia, 1704–1776, 143; see also 453. And see *Hamilton's Itinerarium*, 1744 (ed. by A. B. Hart), 24.

the clock faces were on the eastern and western ends of the building at the attic level, having under each face a masonry structure like the casing of a grandfather's clock.[111]

In February, 1752, the superintendents of the State House were directed to construct a suitable room adjoining the southeastern corner of the building for the accommodation of the committees of the House.[112] This committee-room was the library [113] into which, according to the story told by John Adams,[114] Washington darted when Congress was urged to place the Virginian in command of the army. Upon the completion of the structure the building of the State House

[111] Description of State House written in 1774, in 23 Pa. Mag. Hist. and Biog. 419; description and picture of building in *Columbian Magazine* for July, 1787; Birch, *Views of Philadelphia*, view of Back of State House; Stephens, Philadelphia Directory for 1796, appendix, p. 68; Brabazon, "Our Earliest Civic Center," 34 *Arch. Rec.*, 1, 16. References in Votes of Assembly and in Minutes of Provincial Council are to a clock and not to clocks. House Jour. 1792/3, Appendix, Report of Register General, Book B, shows the purchase of ropes for weights, which were doubtless under the clock faces.

[112] Votes, IV, 213. Eastburn's Plan of Philadelphia, 1776, showed it to be east of the State House and immediately south of the passageway to the eastern wing Its appearance was shown in *Columbian Magazine* for January, 1790, facing p. 25. The Votes contain references to the use of this room (V, 182, 189; VI, 6) and it is referred to in Minutes of General Assembly, Sept. 27, 1786; Pa. Col. Rec., XV, 115; House Jour., Jan. 25, 1791, and April 4, 1793; Joint Resolution of March 17, 1802, Laws 1801–3, p. 284. It is called the committee-room.

[113] A set of the English statutes at large was bought before the building of this room (Votes, IV, 31, 63; see also pp. 31, 114, 115 as to maps), more law books were bought in 1752 (Votes, IV, 217, 230) and on January 16, 1753 (Votes, IV, 237) the Assembly directed Speaker Norris to procure such books as were suitable and necessary for the use of the House and directed the trustees of the loan office to supply the funds. He paid £ 850 for books. (Votes, IV, 267). Later £ 50 were spent for a map. (Votes, IV, 477.) On December 26, 1754, the Speaker's brother, Charles Norris, was made librarian. (Votes, IV, 357, 477.) On the library see also Votes, V, 182, 189, 194, 509, 560, VI, 422, 425; Jour. of House of Rep. of Com., I, 159, 243, 480; Pa. Col. Rec. (Min. of Sup. Ex. Coun.), XI, 309; XII, 586, 699; XIII, 576; XVI, 72; *Pennsylvania Packet*, April 23, 1779; Burnaby, *Travels in North America*, 1st ed., 44, 3d ed., 59, 60; Chastellux, *Voyages dans l'Amerique Septentrionale*, 1786 ed., I, 185; House Jour., Jan. 25, 1791; Burnett, Letters of Members of Continental Congress, IV, 173; note 121.—The second floor of the western wing of the State House provided room for another library from 1740 to 1773—that of the Library Company of Philadelphia. The company moved to Carpenter's Hall in 1773 and to a building on Fifth Street in 1790. (Votes, III, 353, 354; VI, 346; Bulletin of Library Company, Dec., 1929.) Its books, of course, did not constitute the Assembly library. On the company library see also Kalm, *Travels into North America*, I, 44, 45; *Journals of Manasseh Cutler*, I, 282; note 177.

[114] *Works of John Adams*, II, 417.

and its wings was finished.[115] Walls starting from the far sides of the wings inclosed the yard, which then extended half way to Walnut Street.[116] Nothing remained to be built by the Province.

Other buildings, however, had been contemplated. On February 20, 1735/6, the Assembly had resolved that when lots which Andrew Hamilton had bought on Chestnut Street at the corners of Sixth and Fifth Streets should be conveyed to trustees named by the Assembly the lots should be held for the erection within the next twenty years of two public buildings, to be of like outward form, structure and dimensions, the one for the use of the County, and the other for the City, of Philadelphia, each paying a proportionate share of the cost of the ground and each paying the cost of erecting its building.[117] A price of fifty pounds was afterwards placed on each lot and they were duly bought.[118] But the buildings contemplated in 1736 were not erected until more than fifty years later.

We can now see the State House as it was at different periods. In the fall of 1735 the walls and the roof were in

[115] See views of State House in *Gentleman's Magazine*, September, 1752; Heap's East Prospect of Philadelphia, 1753, in Jefferys, *Topography of North America*, 1768; Reed, *Map of Philadelphia*, 1774; *Columbian Magazine*, July, 1787. On the stairway of the State House is a full length portrait of the French minister, Chevalier Gerard, by Charles Wilson Peale. In the background is a view of the State House showing the original steeple, belfry and wings. See also note 144.—The wings were not connected with the building by open arcades but by porticos, open on the north but with solid walls on the south.

[116] *Gentleman's Magazine*, August, 1753. Fencing the grounds was proposed in October, 1732. (Votes, III, 184.) A wall was ordered in 1739 (Votes, III, 347) but it was unfinished two years later. (Votes, III, 432, 434.) See plan of Philadelphia printed with Heap's East Prospect of Philadelphia, 1753, in Jefferys, *Topography of North America*, 1768. On extending the wall in 1770 to include new ground see Votes, VI, 251, 258, 261, and description of State House, written in 1774, in 23 Pa. Mag. Hist. and Biog. 417. On later alterations see Act of Sept. 30, 1791, sec. 4. On the yard as it was towards the end of the century see Pennsylvania Archives, X, 420; *Columbian Magazine*, IV, 25; Davies, *Plan of Philadelphia*, 1794; Stephens, *Plan of Philadelphia*, 1796; Birch, *Views of Philadelphia*, plan of city and views entitled Back of State House and State House Garden; note 145

[117] Votes, III, 276.

[118] Laws of 1761–2 session, pp. 167, 172; Act of April 8, 1785. The city bought its lot about the end of 1763: Minutes of Common Council of Philadelphia, 1704–1776, 695; Votes, V, 493. See also Act of March 29, 1787, cited in note 151. Each lot measured fifty by seventy-three feet. (Laws 1761–2, pp. 170, 171.)

place and the Assembly-room was being used although its walls were unplastered and some of its windows were without glass. At least one of the wings was being built; but no tower had been planned. Ample grounds had been secured. They extended along Chestnut Street from Fifth to Sixth and reached half way to Walnut Street. Of these grounds the Assembly was about to reserve space to the east and the west of the State House for city and county buildings.

By the early seventeen fifties the State House as planned had been finished, a structure to be used as a library and a committee-room had been added to the southeastern corner of the Assembly-room and an impressive tower over thirty feet square [119] had been added to the southern side of the building, providing an attractive stairway to the upper floor. Above the present brickwork of the tower was a wooden superstructure, including a belfry, which was removed towards the end of the Revolutionary War.[120]

The library just mentioned was described in 1774 by a writer who said [121] that from the Assembly-room "you go through a back door into the Assembly's library, which is a very elegant apartment. It is ornamented with a stucco ceiling, and chimney places. Round the room are glass cases, in which the books are deposited . . . The Assembly only has recourse to this library." After describing other rooms, which have been restored in recent times, the writer told of a platform above the attic, of a bell on which the clock struck, placed under a leaden canopy near the attic, and said that "The other part of the steeple being entirely of wood is in such a ruinous condition that they are afraid to ring the bell, lest by so doing the steeple should fall down." [122]

[119] Brabazon, "Our Earliest Civic Center," 34 *Arch. Rec.* 1, 2; Sims and Willing, *Old Philadelphia Colonial Details*, pl. 19.

[120] See notes 115, 125, 144.

[121] 23 Pa. Mag. Hist. and Biog. 417-419, printed from *The Universal Magazine*, which Samuel L. Wharton circulated in manuscript. A manuscript copy is in the library of the Historical Society of Pennsylvania.

[122] Duché, *Observations*, 12, said in the same year, "Behind and adjoining to the State House was sometime since erected a tower, of such miserable architecture, that the Legislature have wisely determined to let it go to decay (the upper part being entirely of wood) that it may hereafter be built upon a new and more elegant construction."

In addition to the clock bell [123] there was also a "great bell in the steeple," concerning the too frequent ringing of which petitioners living nearby had complained to the Assembly in September, 1772,[124] and it was the latter bell which could not be safely rung in 1774.

The author's statement as to the condition of the wooden portion of the steeple is thoroughly supported by the reported proceedings of the Assembly. He added that the replacing of the steeple was being considered. It was not replaced, however, for a number of years,[125] so that while it is true that some bells were rung in Philadelphia on July 8, 1776, during the public celebration of the declaration of independence,[126] it is quite probable that because of the condition of the steeple of the State House the Liberty Bell was not heard at any time between 1773 and 1781 or possibly 1785.[127]

[123] See Birch, *Views of Philadelphia*, Back of the State House. In December, 1785, the Minutes of the Supreme Executive Council (Pa. Col. Rec., XIV, 597) speak of "that part of the State House roof between the steeple and the turret of the clock bell." See also end of note 106.

[124] Votes, VI, 399.

[125] The Assembly (Feb. 25, 1773, Votes, VI, 452; Jan. 22, 1774, Votes, VI, 512; Oct. 19, 1774, Votes, VI, 549) repeatedly considered the ruinous condition of the wooden part of the steeple; in October, 1774 (Votes, VI, 549) ordered that it be taken down; and on March 18, 1775 (Votes, VI, 581) received a proposal to take down the wooden and brick part as low as the eaves of the House and erect a cupola on the roof of the front building, and deferred decision on this proposal; but apparently it was not until April 2, 1781 (Jour. of House of Rep. of Com., I, 604) that the Assembly directed the Supreme Executive Council "to have such parts of the steeple of the State House as are constructed of wood and in a decayed and dangerous condition, taken down; and the remainder sufficiently and effectively covered, in such manner as may be necessary for the preservation of said building." On proceedings under this order see Pa. Col. Rec. XII, 682, 702, 703, 720, 783; XIII, 16, 49, 99, 139; Pa. Archives, IX, 46, 52, 76, 283; X, 335, 336, 348, 373, 420, 426, 535. As the British army approached Philadelphia in September, 1777, the Supreme Executive Council (Pa. Col. Rec., XI, 306; see also Jour. of House of Rep. of Com., I, 289) ordered that the bells in all public buildings in the city be taken down and conveyed to a place of safety. In April, 1781 (Pa. Archives, IX, 77), the contractor recommended that "all that heavy frame whereon the bell used to hang should come down without delay." Hazard, Register of Pa., II, 370, says that the bell was hung somewhere in 1781. The Minutes of the General Assembly show that an appropriation for hanging the bell in the upper brick story of the tower was made on February 22, 1785.

[126] Burnett, Letters of Members of Continental Congress, II, 8; Christopher Marshall, *Remembrancer*, 94.

[127] Cast upon the bell is a passage of Scripture concerning proclaiming liberty throughout the land in the Jewish year of jubilee, possibly suggested by the fact that the bell was ordered in 1751, fifty years after the granting of the charter of 1701. But there is no authority for the statement that the bell was used to proclaim independence

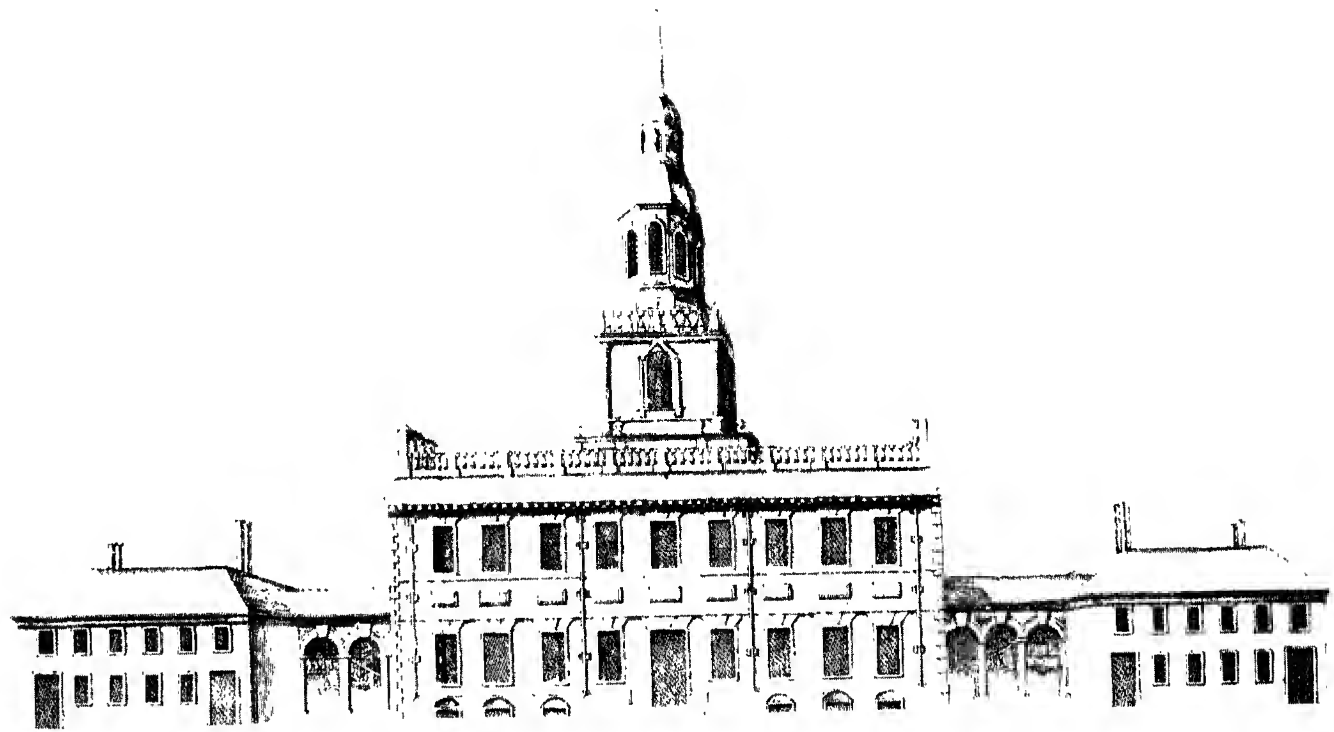

PLATE 5

THE STATE HOUSE, 1752-1781

From Jefferys, "Topography of North America" 1769 Almost identical with a view in the *Gentleman's Magazine* for September, 1752.

Before the opening of the Revolutionary War the grounds and the wall had been extended south to Walnut Street,[128] but no recent changes had been made in the main building or in its wings. During the Revolution, however, two important changes were made—in the eastern end of the second floor and in the tower.

When the Continental Congress returned to Philadelphia in May, 1775, it was given the use of the Assembly-room on the first floor, while the Assembly retired to the room at the southeastern corner of the second floor.[129] The latter room

in 1776, and there are strong reasons for thinking that this ton of metal did not swing back and forth in the rickety steeple in that year. The story of the ringing of the Liberty Bell on July 4, 1776, apparently originated long after that date. See Friedenwald, *The Declaration of Independence*, 134, note; Rosewater, *The Liberty Bell*, chap. VI; Stoudt, *The Liberty Bells of Pennsylvania*, chap. V; Childs, *Views of Philadelphia*, text on the State House; *Poulson's American Daily Advertiser*, March 5, 1828; Watson, *Annals of Philadelphia*, 1830 ed., 345; George Lippard's highly imaginative *Legends of the American Revolution*, published in 1847 and reprinted in 1876; letter by Lippard in *Saturday Courier*, May 15, 1847, p. 2. It is sometimes said that the Liberty Bell was rung to summon the public to meetings at the State House in the years just before the Revolution, but no authority is cited to prove that the bell was rung at the times named and the reports of those meetings in the *Pennsylvania Gazette* say nothing as to bell ringing. Compare earlier rules of Assembly penalizing members who did not appear in the House within half an hour after the Assembly bell ceased to ring (*e g.*, Nov. 5, 1755, Votes, IV, 494; Feb. 13, 1760, Votes, V, 95; Oct. 16, 1767, Votes, VI, 3, 4) with the rules adopted on Oct. 19, 1774, and on Oct. 18, 1775 (Votes. VI, 550, 626) which did not suggest the ringing of the bell but simply penalized members who did not appear "within half an hour after the time appointed." The rules adopted on Nov. 30, 1776 (Journals, I, 99) penalized those members who did not appear "within half an hour after the time of adjournment."—There appear to be relatively few references to the ringing of the State House bell after complaint of too frequent ringing was made in 1772. (Note 124.) When the bell was hung in the upper brick story of the tower in 1785 (note 125), three sounding boards were provided; and we read of it in connection with the summoning of University classes in 1789 and 1791 (note 149); but there are more frequent references to the ringing of the bells of Christ Church (*Pennsylvania Gazette*, Dec. 19, 1787; *Independent Gazetteer*, April 21, 1789; *Pennsylvania Journal*, April 22, 1789; Stoepf, *Travels in the Confederation*, I, 68; Pa. Col. Rec., IX, 42; XIII, 143, 423. 563) and to the payment of money for bell ringing to Joseph Dolby (Pa. Col. Rec., XIV, 176; XV, 121, 597; XVI, 410), who rang the church bells. (Pa. Col. Rec., XIII, 143, 423.) Possibly the explanation is that while the State House bell was rung after 1785, chimes were considered more appropriate for gala occasions.

[128] See notes 86, 116

[129] That Congress used the room on the first floor is shown by Burnett, Letters of Members of Continental Congress, I, 276. and by the fact that Congress sat in a room immediately next to the library-room. (Notes 114, 121.) It does not appear that the Assembly moved out of the building erected for its use Courts continued to use the courtroom (*Dunlap's Pennsylvania Packet*, Sept. 18, 1775; *Pennsylvania Gazette*, Sept. 20, 1775; April 3, 1776; note 64) and that room apparently then, as earlier and

measured twenty by forty feet.[130] It was of sufficient size, for there were only forty Representatives.[131] But in 1776 the State adopted a new constitution which provided for seventy-two Representatives and made the holding of open sessions the normal order of events.[132] The room thus became inadequate. Nothing was done to enlarge it, however, until after the British army had occupied and had left Philadelphia and the Assembly had returned from Lancaster.[133] The size

later, had no doors separating it from the hallway (notes 91, 148), so that secret sessions in it would have been impossible. The council continued to use the council-chamber. (Pa. Col. Rec., X, 268; XI. 535; Jour. of House of Rep. of Com., I. 227.) The only other rooms in the building were the long room, where secret sessions would have been impossible, and the room in the southeastern corner of the second floor. Schoepf, *Travels in the Confederation*, I, 69 (1783), says that Congress had formerly sat on the lower floor and that on the upper floor "there are two halls, for the General Assembly and for the Governor and Council."—For the appearance of the room in which Congress sat, see painting by Pine and Savage, "The Congress Voting Independence," in the hall of the Historical Society of Pennsylvania. It is reproduced as a frontispiece to 29 Pa. Mag. Hist. and Biog. and followed by an article thereon. Trumbull's painting "The Declaration of Independence" is architecturally inaccurate. See entrance from hallway as shown in plan of room at time of reception of French minister in 1778 in Doniol, *Histoire de la participation de la France à l'établissement des États-Unis d'Amérique*, III, 312; Tower, *The Marquis de La Fayette in the American Revolution*, II, 29.

130 Note 96.

131 There were thirty members in 1729 and 1732 (Votes, III, 95, 183), forty in October, 1774 (Votes, VI, 546) and forty-one in October, 1775. (Votes, VI, 622.) The number was increased by an act of March 23, 1776. (Votes, VI, 688, 693, 698; Acts of Com. of Pa., 1775–1781, appendix, c. II.) See note 75.—Desks for members were not provided until long after the Revolution. (*Independent Gazetteer*, Nov. 27, 1786; end of note 140. See also painting by Pine and Savage cited in note 129.)

132 Constitution of 1776, c. II, secs. 17, 13; Jour. of House of Rep. of Com., I, 97. The convention, which met in the State House and which did not confine its governmental activities to constitution-making, had a larger membership: Journals, I, 49, 50.

133 At Lancaster the Assembly had sat in the court house. (Pa. Col. Rec., XI, 362.) The Journals (I, 231) show that on October 30, 1778, after the return to Philadelphia, "A large number of the members met pursuant to adjournment, although not quite sufficient to constitute a quorum: One of the gentlemen addressed his brother members, observing, that the chamber in which they were then assembled was already so crowded that it would be extremely inconvenient for the dispatch of public business; that it would become more so, when the house should be full; that therefore and also to make room for such of the freemen as choose to be present at the debates, he moved that some gentlemen should be appointed to visit and examine the different public buildings in the city and report in what place the house might be most conveniently accommodated: The inconvenience being obvious, the motion was unanimously agreed to, and three gentlemen appointed on that service." On November 2, "The gentlemen appointed to examine the public buildings, in order that the house might be more conveniently accommodated, reported, that they had made the necessary enquiries, but that all the buildings where the house could be tolerably accommodated, were so taken up with public stores, &c that they recommended the place where

of the room was then doubled by so changing the interior walls as to extend the room across the entire eastern end of the building.[134] Thus enlarged the room was occupied by the Assembly until long after Congress left Philadelphia in 1783;[135] it may have served the Federal Constitutional Convention of 1787 for some of its sessions;[136] it served the

they were then assembled, with some enlargement and alteration as most suitable; they then pointed out the manner in which the proposed enlargement and alteration might be made; which being agreed to, the gentlemen were desired to procure workmen &c to make the same with all possible expedition: In the mean time it was agreed to meet at the college." See also *Pennsylvania Packet*, Nov. 7, 1778. Work was still being done on this room in October, 1779 (Journals. I, 385) and a committee report on this work was made on March 24, 1780. (Journals, I, 454. See also 636.) In the following fall we have the first express statement that the Assembly was again meeting in the State House. (October 23, 1780, Journals, I, 525; see also March 24, 1781, Journals, I, 653.) In November, 1780, a paper reported a meeting of citizens in the Assembly-room; in December it referred to that meeting as having been held in the State House. (*Pennsylvania Packet*, Nov. 21, Dec. 12, 1780.) Chastellux, *Voyages dans l'Amerique Septentrionale*, 1786 ed., I, 186, described a session of the Assembly in the State House on December 5, 1780, which he attended with Lafayette and others.

[134] No description of the alterations appears to have been published at the time they were made, but a correspondent quoted by the *Pennsylvania Gazette* and the *Federal Gazette* on March 18, 1789, said that the apartment above what was in 1789 the hall of the General Assembly was of the same dimensions as the room below. On November 13, 1781, the Council agreed that on the next day it would "meet the General Assembly in the Assembly-room, being larger and more convenient for the purpose than the Council Chamber." (Pa. Col. Rec., XIII, 111.) Congress was then meeting downstairs, so that the Assembly-room was the enlarged room upstairs. See also Pa. Col. Rec., XIII, 413.

[135] Robert E. Pine, who painted a large portion of "The Congress Voting Independence" (see note 129), advertised in October to December, 1784 (*Freeman's Journal*, Nov. 3, 10, 24; *Pennsylvania Packet*, Oct. 23, 25, 27, 30; Nov. 3, 10, 15, 29; Dec. 1, 2), exhibitions of his pictures in the Congress Chamber at the State House. As the room was given that name in the advertisements and as exhibitions were held on some days during which the Assembly was in session, the Assembly must have been still sitting upstairs. The advertisements are not uniform in phraseology. On the last three dates Pine said that the pictures had been replaced in the room, "the sessions of the Supreme Court being over." The minutes of the court show the jury trial of Edward Connard on November 27. The eastern room could be used as a courtroom because it was not being used by the Congress or the Assembly; and it was preferable to the regular courtroom in winter because two stoves had been placed in the Assembly-room in 1772 (Votes, VI, 350), whereas the regular courtroom was not adequately heated in cold weather. (Note 148.)—On November 27 the Assembly offered to Congress "such apartments in the State House, and other buildings and apartments, being the property of this commonwealth as have been heretofore used and occupied by Congress, or by their ministers and officers."

[136] Cutler, writing on July 13, 1787 (*Journals of Manasseh Cutler*, I, 262; Farrand, Records of Federal Convention, III, 58), after telling of seeing a court in session in the courtroom, said, "The hall east of the aisle is employed for public business. The

Assembly on other occasions while the Federal Convention occupied the room below;[137] it was used by the state convention which considered and ratified the Federal Constitution[138] and either it or the room downstairs was used by the convention which framed and adopted the state constitution of 1790, the Assembly using one room and the convention the other.[139] The room upstairs was the meeting-place of the State Senate from December, 1790, when the Assembly became a bicameral body, until the seat of government was removed to Lancaster

chamber over it is now occupied by the Continental Convention, which is now sitting but sentries are planted without and within—to prevent any person from approaching near— who appear to be very alert in the performance of their duty." The latter sentence is not entirely clear. If it means that sentries were planted both without and within the chamber, then, as he could not have seen within the room, he was doubtless relying upon the statements of others as to the sentries "without and within." He gave no other indication of having gone upstairs. The fact that he also said (I, 282) that the Declaration of Independence had been adopted in Carpenter's Hall casts some shadow upon his statement concerning the location of the meeting in 1787. Taking the two statements together, it seems possible that his guides were steering him away from the important room. Farrand, III, 59, note, quoted from Watson, *Annals of Philadelphia*, the assertion "of an elderly gentleman" that the Convention met upstairs. The passage was in the 1843 edition of Watson, I, 402, but not in the 1830 edition. The statement of an unnamed person so long after the event carries but limited weight. On the other hand, the *Columbian Magazine* for July, 1787, said that the sessions were held "in the same hall which enclosed the patriots who framed the Declaration of Independence." The *Diary of Jacob Hiltzheimer*, a member of the General Assembly, for September 5, said that the Convention had been meeting downstairs and that the Assembly, which had been in recess, would meet upstairs. The Minutes of the Assembly for that date appear to make the same statement. Madison's Debates for September 17 quotes a remark by Franklin about looking often at a carving on the President's chair which appears to show that from time to time through the Convention he had been looking at the chair in which Washington sat on September 17. Mease, *A Picture of Philadelphia* (1811), 319, says that the Convention sat in the east room on the first floor. It thus seems probable that the Convention met downstairs usually if not always, although it is possible that when the Assembly was not in session the choice of the Convention as to its meeting-place depended upon whether it gave more weight to the accessibility of the lower room and the associations connected with it or to the desire for the utmost secrecy at some stages of its proceedings. Secrecy may have been more desirable in June and July than it was later on. Yet we must remember that during the war, when there was some need for secrecy, the Congress sat downstairs and the Assembly upstairs. It is also possible that the use of the courtroom in July, 1787, when Cutler was in Philadelphia, made it desirable for the Convention to sit upstairs while the court was in session.

[137] Minutes of General Assembly, Sept. 5, 1787; Lloyd, Pennsylvania General Assembly Debates for the same date.

[138] *Diary of Jacob Hiltzheimer*, 158; *Pennsylvania Gazette* and *Federal Gazette* for March 18, 1789.

[139] With Pa. Col. Rec., Minutes of Supreme Executive Council for Nov. 23, 1789, compare *Diary of Jacob Hiltzheimer*, 159, for Feb. 5, 1790.

PLATE 6

THE STATE HOUSE AND VICINITY, 1790

From *Columbian Magazine*, January, 1790. View from southwest. (1) Protestant Episcopal Academy; not yet completed; in reality it was west of the site shown. (2) County Court House, to become Congress Hall in the following December; enlarged in 1793. (3) State House, the steeple had not been restored as here shown. Attached to the southeastern corner of the building was the committee room or library shown above. The City Hall had not been erected. (4) The building of the American Philosophical Society, completed in 1789 and occupied by the University of the State of Pennsylvania (see note 149). (5) The home of the Library Company of Philadelphia, occupied in the following October. It was on the east side of Fifth Street. (6) Carpenter's Hall; east of Fourth Street. In the foreground is the Sixth Street portion of the wall surrounding the square.

in 1799.[140] Probably no further change was made in the room until 1802, when the State granted permission to Charles Wilson Peale to use for his museum the whole of the upper story and the Assembly-room on the first floor.[141] In this museum the long room was reestablished and the room on the second floor which had been used by the Assembly was reduced to the size which it had had in colonial times.[142]

The only other structural change of importance which

[140] The Senate met in the State House. (Sen. Jour., Dec. 17, 1790.) An old citizen, writing in *Poulson's American Daily Advertiser* for Dec. 6, 1828 (see also Hazard, Register of Pa., II, 366), described the room on the second floor as used by the Senate in 1794. The court room down stairs was unavailable, for Pennsylvania courts sat in the building (note 64); the Supreme Court of the United States met there on Feb. 7, 8, 1791 (note 57) and the Federal Circuit Court later in that month. (*Federal Gazette*, Feb. 11, 12, 1791.) The Senate Chamber had doors (Sen. Jour., March 16, 1791; April 2, 5, 9, 1794), while there were no doors between the court-room and the hallway. (Note 148.) The Senate Chamber was the usual meeting-place for joint sessions of the two Houses (Sen. Jour., Dec. 17, 21, 1790; Feb. 28, March 1, Aug. 29, Dec. 5, 14, 17, 1793; April 2, 1794; Feb. 26, 1795; Dec. 12, 1796; Jan. 10, Dec. 9, 1797; Dec. 7, 1798; compare House Jour., Jan. 12, 1796; Sen. Jour., Dec. 7, 1799) and the room was large enough for the members of both Houses to be seated there. (See Sen. Jour., Dec. 21, 1790; Dec. 17, 1793.) On April 4, 1796, the Senate proposed an appropriation "for making a committee-room for the use of the Senate *over* that now used by the House of Representatives." This was on the last day of the session and when the House did not concur the Senate receded. Later on the Senate made a further but unsuccessful effort to secure a committee-room. (Sen. Jour., Jan. 22, Feb. 28, 1798.) When it is recalled that there was a committee-room, built in 1752 (notes 112, 113), immediately southeast of and adjoining the Assembly-room on the first floor—and this one-room building was used by the House as a committee-room in the seventeen nineties (House Jour., April 4, 1793; Joint Resolution of March 17, 1802, Laws 1801–02, p. 283)—it will be realized where the Senate sat when it proposed the making of a new committee-room for itself over that which was used by the House of Representatives and where the House of Representatives sat at that time.—The Senate Journal (March 16, 1791; Dec, 14, 1798) speaks of the gallery of the Senate Chamber. See also *Pennsylvania Gazette*, Dec. 12, 1787. This was doubtless simply the space reserved for visitors: see note 147.—On procuring "a competent number of pine tables, with drawers, locks and keys, for the accommodation of members of" the House, see House Jour., Dec. 14, 1790.

[141] Joint resolution approved March 17, 1802, Laws 1801–02, p. 283.

[142] Mease, *A Picture of Philadelphia*, 312; Colton, "Peale's Museum," 75 *Pop. Sci. Mon.* 221, 229. The smaller room was the room in which the skeleton of a mammoth was exhibited. See also Janson, *The Stranger in America*, 193. The appearance of the long room is shown in Peale's Portrait of the Artist in His Museum, in the Pennsylvania Academy of Fine Arts, reproduced in the academy's Catalogue of Peale Portraits and in Art in America, Univ. of Chi. Press —The museum had been located in the building of the American Philosophical Society since 1794 and part of it remained there until 1811: *Early Proceedings of the American Philosophical Society*, May 30, June 20, 1794; May 7, 1802; June 15, Sept. 21, 1804; Jan. 17, 1806; Dec. 6, 1811; *Philadelphia Gazette*, Sept. 29, 1802.

was made in the State House during the Revolution was ordered in April, 1781, when the Supreme Executive Council was "authorized and directed to have such parts of the steeple of the State House as are constructed of wood and in a decayed and dangerous condition, taken down; and the remainder sufficiently and effectually covered, in such manner as may be necessary for the preservation of said building." [143] Everything above the present brickwork of the tower was removed and the brickwork was covered with a low, sloping roof surmounted with a slender central finial, a covering which remained until the present steeple, with its clock, was erected in 1828.[144]

In the years immediately following the Revolution the appearance of the State House yard was greatly improved, so that when the Constitutional Convention assembled there were "gravel walks, shaded with trees, a pleasant lawn, and several beds of shrubs and flowers." [145] The State House

[143] Note 125.

[144] *Poulson's American Daily Advertiser*, Feb. 22, March 3, July 4, 1828; Hazard, Register of Pennsylvania, I, 152, 176, II, 144. The building without a steeple is shown in Davies, *Plan of Philadelphia*, 1794; Birch, *Views of Philadelphia*, Back of the State House, 1799; Desilver, *Map of Philadelphia*, 1819; Wilson, *Picture of Philadelphia for 1824*, p. 318; C. G. Childs, *Views of Philadelphia*, 1830, View of State House, 1828.

[145] *Columbian Magazine* for July, 1787. The same magazine for January, 1790, said of the yard, "It is inclosed on three sides by a brick wall; the State House, County Court House &c constituting its boundary towards Chestnut Street. This area has of late been judiciously improved under the direction of Samuel Vaughan, Esq. It consists of a beautiful lawn, interspersed with little knobs or tufts of flowering shrubs and clumps of trees well disposed. Through the middle of the gardens runs a spacious gravel walk, lined with double rows of thriving elms and communicating with serpentine walks which encompass the whole area. The surrounding walks are not uniformly on a level with the lawn, the margin of which, being in some parts a little higher, forms a bank which in fine weather affords pleasant seats. When the trees attain to a larger size it will be proper to place a few benches under them, in different situations, for the accommodation of persons frequenting the walks." Swanwick, *Poems*, 94, tells of a walk in the yard on June 30, 1787. See also *Journals of Manasseh Cutler*, I, 262; Pa. Archives, XI, 674; *Federal Gazette*, April 2, 1789; Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 131, 164.—On earlier proposals for the improvement of the yard see Votes, III, 184, for Oct. 17, 1732, and V, 284, for Oct. 22, 1763.—The Acts of Feb. 20, 1735/6, and Feb. 17, 1762, provided that no part of the ground south of the State House should be used for erecting any sort of building thereon, but that it should remain a public green and walk forever. In September, 1785 (Minutes, Sept. 17, 28; Pa. Col. Rec., XIII, 692), the Assembly authorized the Council to lay out the ground according to the original design and to draw on the treasury for such sums as they might find necessary. Under this authorization the Council spent £983. (Pa. Col. Rec., XIV, 286, 552; XV, 222; Minutes of General Assembly, 1788, pp. 191, 192.

received extensive repairs, [146] although nothing came of proposals to erect a gallery in the Assembly-room [147] and to construct a partition separating the room of the Supreme Court from the public hallway, filling in the three wide open archways which had always exposed the court to distractions

See also Pa. Archives, X. 373, 420; XI. 674; Pa Col Rec., XVI, 369. On the yard as it was towards the end of the century see end of note 116.—On improvements in front of the State House and around the square outside the wall see Minutes of Assembly, Feb. 22, 1785; Pa. Col Rec., XIII, 602; *Pennsylvania Gazette*, Feb. 24, 1790; Jour. of Sen. of Pa., II. 10. The gateway referred to in the minutes of Feb. 22, 1785, may be shown in Davies. *Plan of Philadelphia*, 1794.

[146] Minutes of General Assembly, 1781, Report of Committee of Accounts, pp. 29, 33, 42, 43; Minutes of Feb. 4, 1783; Sept. 9, 22, 1784; Feb. 22, Nov 28, 1785; Sept. 27, 1786; March 10, 25, 1789; Pa. Col. Rec., XIV. 213, 231. 235, 285, 406, 495, 532, 580, 597; XV, 88, 90, 103, 337, 580; XVI, 90; Pa. Archives X, 373, 542, 547; XI, 558, 559.

[147] In the Assembly on March 10, 1786, it was proposed "that the Supreme Executive Council be requested to cause a gallery to be erected for the accommodation of such persons as choose to attend the debates of the General Assembly." Consideration was postponed. On Sept. 5 a committee was appointed to contract for repairs to the roof of the committee-room and to report an estimate of the expense of erecting a gallery in the Assembly-room. On Sept. 27 the committee reported a contract for a roof for the committee-room, but apparently nothing was said as to erecting a gallery. See also *Independent Gazetteer*, Nov. 27, 1786, p. 3, col. 2. A committee report in Votes, V, 324, 325, for March 6, 1764, refers to the gallery of the House; and Thomas Lloyd, in Proceedings and Debates of the General Assembly, for Sept. 29, 1787, says (p. 140) that a "ludicrous circumstance occasioned a loud laugh in the gallery." See also *Connecticut Courant* for Oct. 1, 1787, and *Salem Mercury* and *Pennsylvania Herald* for Oct. 2. Apparently, however, the gallery was merely the space outside the bar or the audience in that space. The *Pennsylvania Packet* for Aug 11, 1778, tells of the reception of the French minister by Congress and says that there was an audience of one hundred gentlemen without the bar. The seating arrangement for that reception and the location of the bar are shown in Doniol, *Histoire de la participation de la France á l'établissement des États-Unis d'Amérique*, III, 312; Tower, *The Marquis de La Fayette in the American Revolution*, II, 29. The *Pennsylvania Gazette* for Dec. 12, 1787, says that at a session of the state convention for considering the ratification of the Federal Constitution, which was held upstairs (note 138), a speech by McKean was very acceptable to the gallery. Brissot de Warville. *New Travels in the United States of America*, 248, telling of a visit to the Assembly on September 6, 1788, says, "There were about fifty members present, seated on chairs inclosed by a balustrade. Behind the balustrade, is the gallery for spectators." The *Pennsylvania Gazette* and the *Federal Gazette* for March 18, 1789, tell how many persons could be accommodated in the Assembly-room within the bar and how many "in the gallery without the bar," and then, referring to the new Court House, where there was an elevated structure for visitors (*Gazette of the United States*, Dec 4, 1790), tell of room "in the gallery and without the bar." See also latter part of note 140. On May 31, 1790, Gerry declared in Congress, "The State House of Philadelphia has no gallery" (*Pennsylvania Gazette*, June 9, 1790); and on July 6 Burke said that there was "no gallery to the buildings at Philadelphia." (*Pennsylvania Gazette*, July 21, 1790.)

from persons who had no business before it.[148] A lot upon the Fifth Street side of the yard was granted to the American Philosophical Society for the erection of a building which was under way in 1787, although it was not completed until 1789;[149] and, in accordance with resolutions adopted by the

[148] The Minutes of the General Assembly for Nov. 23, 1786, report a motion for the appointment of a committee "to report an estimate of the expense of dividing, by a partition from the entry, that part of the State House where the Supreme Court usually meet, and the expense of setting up a stove therein." Consideration was postponed, and when the resolution was further considered on Nov. 30 the Assembly again refused to adopt it. For an earlier effort see Minutes of Assembly, Jan. 21, March 1, 8, 1784. Manasseh Cutler (*Journals*, I. 262) described the State House as he saw it on July 13, 1787, writing, "This is a noble building; the architecture is in a richer and grander style than any public building I have before seen. The first story is not an open walk, as is usual in buildings of this kind. In the middle, however, is a very broad cross-aisle, and the floor above supported by two rows of pillars. From this aisle is a broad opening to a large hall, toward the west end, which opening is supported by arches and pillars. In this hall the courts are held, and, as you pass the aisle, you have a full view of the court." —Birch, *Views of Philadelphia*, shows the back of the State House in 1799. At that time stove pipes came through the top panes of the two western windows and crossed the wall diagonally to enter chimneys from outside the building. I have not found authorization of alteration in entrance or heating arrangements, unless under the name of plastering and repairs, although I have read the Minutes of the one-chamber General Assembly down to its expiration in 1790, the Senate Journals from then down to 1799, when the legislature moved to Lancaster, the House Journals from 1790 to the end of the 1795/6 session, when the set at the Library of Congress ends, and all the financial reports printed with those various journals. See Minutes of General Assembly, March 10, 20, 25, 1789; Pa. Archives, XI, 559.

[149] See *Columbian Magazine*, July, 1787, Cutler, *Journals*, I, 263. The lot was granted by Act of March 28, 1785, despite Acts of 1735/6 and 1762, cited in note 145. See also Votes of Assembly, VI, 166, 167; Minutes of Assembly, Nov. 12, 1785. Further privileges were granted by Act of March 17, 1786. The first regular meeting of the Society in the building was on Nov. 13, 1789 (*Early Proceedings of American Philosophical Society*, 17[illegible]). For appearance of building at that time see frontispiece of volume cited; Wild, *Panorama of Philadelphia*; Birch, *Views of Philadelphia*, view of Back of State House.—In 1789 the building became the home of the University of the State of Pennsylvania. The property of the College of Philadelphia had been vested in trustees of the University by Act of Nov. 27, 1779, and restored to the College by Act of March 6, 1789. Meanwhile other property had been vested in the University (Act of Sept. 22, 1785) and this property did not pass to the College by the Act of 1789. The two institutions were united by the Act of Sept. 30, 1791. After the passage of the Act of 1789 the crippled University leased from the Philosophical Society all of its building except the two south rooms on the second floor, "the rent to commence as soon as the house is in tenantable order." (*Early Proceedings*, 170–172, March, 1789. See also *Federal Gazette*, March 13, 1789.) The Supreme Executive Council of the State (Minutes of June 11, Sept. 25, 1789) [illegible] the University to ring the State House bell when the Assembly was not in session in order to give notice to students of the time to attend classes. *Dunlap's American Daily Advertiser* (May 9, 1791) contained advertisements of lectures and instruction in German at the University from six till a little after seven every morning [illegible] that the State House bell would ring at six during the summer [illegible]. The University's lease did not expire until the summer of 1794. *Early Proceedings*, [illegible] 219, 222.

Assembly some fifty years before,[150] the County of Philadelphia undertook the building of a court-house at the northwestern corner of the yard.[151] The construction of the court-house commenced just before the Convention assembled and proceeded during its sessions.[152] The building was completed early in 1789.[153] It was turned over to the use of the United States when the seat of the Federal Government was moved to Philadelphia in December, 1790,[154] and both

[150] Note 117.

[151] By the Act of Feb. 26, 1773, the Assembly authorized the County Commissioners to borrow the necessary funds, buy a site and erect a jail, workhouse and house of correction, paying the indebtedness upon the completion of the work by selling the old jail at the southwestern corner of Third and Market Streets and by raising additional funds, if necessary, by taxation. In 1776 the new jail at the southeastern corner of Sixth and Walnut was taken over by Congress for use as a military prison and the old jail was again used by the County of Philadelphia. (Acts of Aug. 27, 1778; Oct. 8, 1779.) By Acts of April 8 and Sept. 13, 1785, the County Commissioners were directed to sell the property at Third and Market and after paying a portion of the proceeds to commissioners appointed to secure a court-house and a prison for the newly-created Montgomery County to apply three thousand pounds to the building of a court-house for Philadelphia County on the northwestern corner of the State House lot. At the same time other provision was made for erecting a building for the city on the northeastern corner of the lot, with the stipulation that the President or Vice President of the State in Council should pass upon the plans of the two Philadelphia buildings "in order that their outward forms may be alike and as uniform as possible." (See also Pa. Col. Rec., XIII, 589, 653; XIV, 284, 358, 366, 456, 483; XV, 323.) The Council approved a plan for the Court House on March 8, 1787. (Pa. Col. Rec., XV, 175.) By the Act of March 29, 1787, the lots of the county and the city were each extended fifteen feet in depth so that the building line on Chestnut Street might be moved back that distance. (Minutes of General Assembly, March 6, 15, 26, 1787.) The appearance of low buildings which had been on the old line is shown in the *Columbian Magazine* for July, 1787.—The building at Sixth and Chestnut was thus paid for largely from the proceeds of the sale of the jail and workhouse at Third and Market, and that property had remained available largely because the new jail which had been built to supplant it had been used by Congress as a military prison during the Revolution.

[152] *Columbian Magazine*, July, 1787; *Journals of Manasseh Cutler*, I, 263. Obviously building commenced after the passage of the Act of March 29, 1787, cited in note 151. "1787" was carved in the marble band course directly under the balcony.

[153] Minutes of General Assembly, March 4, 5, 1789; *Pennsylvania Gazette*, March 18, 1789; *Federal Gazette*, Jan. 31, March 7, 18, April 3, 13, 1789; March 13, Sept. 22, 1790.

[154] On March 5, 1789, the Assembly tendered to Congress the use of the State House and the County Court House should Congress at any time choose Philadelphia for the temporary residence of the Federal Government. Exclusive jurisdiction over Philadelphia was never offered. (See Act of Sept. 14, 1789; Minutes of Convention of Commonwealth, 1787, pp. 25, 26; Hazard, Register of Pa., IV, 264.) Congress chose Philadelphia as a temporary residence by Act of July 16, 1790. A correspondent to the *Pennsylvania Gazette* and the *Federal Gazette* for March 18, 1789, said that the great hall (on the first floor) of the Court House was capable of accommodating 100

Houses of Congress held their sessions within its walls for the next ten years, the building being enlarged in 1793 to meet an increase in the membership of the House of Representatives.[155]

members and nearly 500 auditors in the gallery and without the bar. The gallery, said the *Gazette of the United States* for Dec. 4, 1790, would hold about 300 persons. Commissioners of the city and county made alterations in the Court House to adapt it to the uses of Congress: *Federal Gazette*, Sept. 22, 1790; *Gazette of the United States*, Dec. 15, 1790. See also Jour. of House of Rep. of Pa., Dec. 28, 31, 1790; Dec. 30, 1795; Act of Sept. 30, 1791. The *Columbian Magazine* for January, 1790, shows how the Court House appeared at that time, viewed from the southwest. Birch, *Views of Philadelphia*, shows how its front appeared then and later from the northeast. The building when constructed was of the same size as the subsequently-built City Hall. It therefore measured about fifty by sixty-six feet, with a projecting bay on the south side reaching from the ground to the roof. So many persons were able to crowd into the Senate Chamber on the second floor even before the building was enlarged (as at the time of Washington's second inauguration: *Gazette of the United States*, March 6, 1793; see also same paper for Dec. 11, 1790; Nov. 7, 1792; *National Gazette*, Feb. 20, March 6, 1793) that the chamber must have occupied before the enlargement some space which was afterwards devoted to other purposes. In 1793 the building was extended southward twenty-seven feet. But the cupola remains where it was first placed instead of being in the present centre of the roof.

155 The Constitution made the initial membership 65. The Act of April 14, 1792, raised the number to 105. On the need for increased accommodations see message of Governor Mifflin to the Assembly: House Jour., Dec. 18, 1792; Sen. Jour., Dec. 19. By Act of April 11, 1793, the Assembly appropriated $6667 for enlarging the Court House, granted the necessary ground and directed the building of a gallery in the Senate chamber. There was already a gallery in the House. (Note 154.) When Congress reassembled in December the building had been enlarged (*Federal Gazette*, Dec. 2, 1793), in spite of a very severe epidemic which had swept over the city (Jour. of Sen. of Pa., address by Governor on Dec. 5, 1793; M. Carey, *A Short Account of the Malignant Fever*; *Diary of Jacob Hiltzheimer*, 195; Burd Papers, 180, 182; *National Gazette*, Sept. 11, 21, 25, Oct. 23, 1793; *Federal Gazette*, Oct. 24, Nov. 14, Dec. 11 (supplement), 1793; *Pennsylvania Gazette*, Nov. 20, 1793; Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 111; Poulson's Almanac, 1795), and preparations for the gallery had been made although the commissioners had gone beyond their appropriation without building it. (Jour. of House of Rep. of Pa., Feb. 19, 1794; Jour. of Sen., same date; Act of April 11, 1795.) The Senate of the United States had repeatedly rejected resolutions for open sessions while legislating (see, *e.g.*, *National Gazette*, April 9, Nov. 21, 1792; Feb. 9, 13, 1793); but on Feb. 20, 1794 (Annals of Congress, IV, 47) it resolved that except when ordered otherwise its legislative sessions should be open "as soon as suitable galleries shall be provided for the Senate chamber." By Act of April 11, 1795, the Assembly made a deficiency appropriation and granted $1000 additional for building a Senate gallery. (See also Jour. of Sen. of Pa., VI, Report of Register General for 1795, p. 15.)—The interior of the building is described in a letter from Theophilus Bradley, a member of Congress, to his daughter in Dec., 1795, printed in *Pa. Mag. Hist. and Biog.*, VIII, 226. See also *Gazette of United States*, June 22, 1791, p. 2, col. 1; Weld, *Travels*, 1st ed., 6; Wansey, *Journal*, 111; Moreau de Saint-Méry, *Voyage aux États-Unis de l'Amérique, 1793–98*, pp. 375, 376; Murrell, *A History of American Graphic Humor*, p. 44, No. 37; *Poulson's American Daily Advertiser*, Aug. 25, 1829; Hazard, Register of Pa., IV, 142.

We are now able to picture to ourselves the scene presented when the justices of the highest court of the land, escorted from their lodgings by a group of Philadelphia lawyers, entered the State House upon the seventh of February, 1791,[156] and took their seats upon the bench. The room in which they sat was undoubtedly upon the western side of the first floor. That room had been for at least forty years, and probably for over fifty years, the home of the Supreme Court of the Province and Commonwealth, where its justices had served at times as an appellate court and at times as a court of the first instance. Jury trials were held there; the justices of the state court had held a court of oyer and terminer in the room two weeks before[157] and it was to be used by the federal circuit court for a jury trial later in February;[158] it served more than one purpose; but it was primarily the most important courtroom in Pennsylvania.[159] And it was one of the most attractive courtrooms in the United States.[160] It was forty feet square, with a lofty ceiling,[161] and had three large windows to the south facing the well-laid-out State House yard, three similar windows to the north facing Chestnut Street, with a wide space, paved and graveled, between the building and the roadway,[162] and two smaller windows to

[156] Note 57.

[157] Notes 59, 64. The room was still unfinished in November, 1743 (note 103); but we must remember that the Assembly had moved into the State House in 1735, when its room was still unplastered and was without glass in all of its windows. (Note 99.)

[158] Note 60. On the court see also Loyd, *Early Courts of Pennsylvania*, 106.

[159] Note 64.

[160] See *Pennsylvania Gazette* and *Federal Gazette* for March 18, 1789. A view of the room as restored is shown in Plate 7. The restoration was apparently based on Trumbull's Declaration of Independence, a painting which misrepresents the appearance of the room there involved. (End of note 129.) Leading architects who were consulted before the restoration afterwards questioned the cornice and other wood trim in the courtroom. (Letter dated April 23, 1936, from Carl A. Ziegler, chairman of the Committee on Preservation of Historic Monuments of the Philadelphia chapter of the American Institute of Architects, to the author.)

[161] Note 96.

[162] In 1785 the space in front of the State House was paved and graveled and new red cedar posts, turned, were placed along the roadway, with a neat rail of pine. (Minutes of General Assembly, Feb. 22, 1785.) Birch, *Views of Philadelphia*, shows the front of the building in 1798. See also end of note 144.

the west looking towards Congress Hall.[163] The bench must have been upon the western side of the room.[164] Upon the eastern side three wide archways opened into the corridor which ran through the centre of the building from north to south. Probably the Court was disturbed by persons passing along that corridor.

The room, while attractive, was not ideal. Years before the Assembly had refused to supply stoves such as warmed the legislature,[165] and, so far as appears, the room was unheated. Indeed, at best, the character of the entrance would have made the heating of the room difficult. But the weather was comparatively mild on February seventh and eighth.[166]

The Court sat only two days, giving all of its attention to a discussion of the manner of proving the professional attainments of applicants for admission to its bar and to admitting applicants.[167] For those two days the three departments of the Federal Government were housed closer to each other than they had been at any earlier time or than they have been at any time since that term.[168] Congress Hall was only a hundred feet west of the courtroom and between the buildings was a State House wing which was devoted almost exclusively to the uses of Congress.[169] President Washington

[163] Birch, *Views of Philadelphia*, Back of the State House, shows the building from the southwest.

[164] Birch, view last cited, shows a rear entrance to the room and the western windows at such levels as to indicate that the location of the bench was in its natural position opposite to the entrance to the room.

[165] Votes, VI, 350, notes 135, 148; Jour. of House of Rep. of Com., I, 478, 479, 636. See also Minutes of Assembly, Oct. 1789, p. 63; *Diary of Jacob Hiltzheimer*, 47, for Jan. 10, 1782.

[166] The *Universal Asylum and Columbian Magazine* for March, 1791, p. 208, reported meteorological observations in Philadelphia for February. The temperature ranged from 41 to 55 on the seventh and eighth. Most of the remainder of the month was colder. The weather was cloudy and foggy on the seventh; rain fell on the eighth and snow on the ninth.

[167] Note 57. A list of admissions at this term is printed in *Dunlap's American Daily Advertiser*, Feb. 24, 1791.

[168] On August 5, 179[illegible], the Supreme Court again sat in the State House for one day. (Minutes of Supreme Court.) Congress was not then in session. (Journals of Senate and House of Representatives.)

[169] The Supreme Executive Council (Pa. Col. Rec., XVI, 480) placed the building at the disposal of the House of Representatives for its clerk, its committees and the keeping of the papers of the former Congress. The land offices and the doorkeeper of

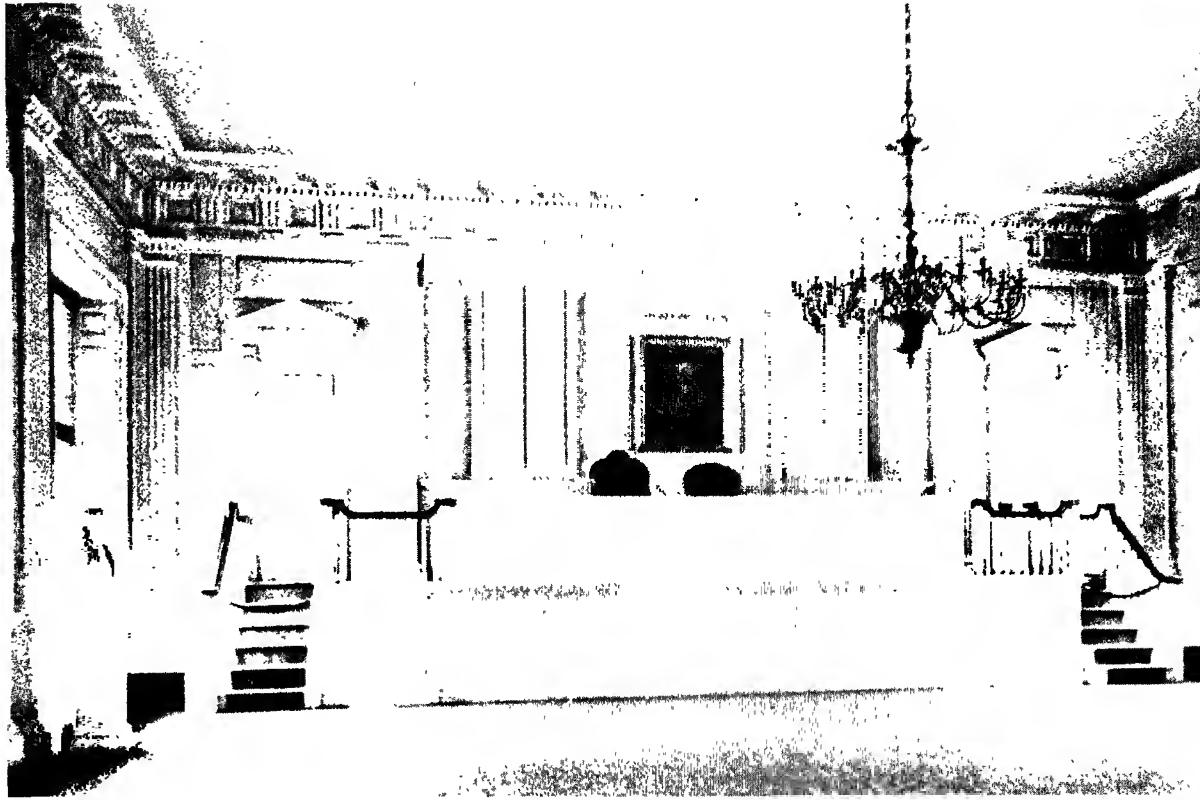

PLATE 7

THE COURTROOM IN THE STATE HOUSE

As restored in 1898. Photographed in 1921. See note 160

was living one block away on the south side of Market Street a short distance east of Sixth in a handsome house, surrounded on three sides by spacious grounds.[170] And not merely were Congress, President and Court close to each other, but the state government was near by.[171] The House of Representatives of Pennsylvania met across the hallway from the Supreme Court in the room which had been the home of the Assembly before 1775, Congress Hall from then until 1783, and again the Assembly-room in recent years until a new constitution had made the Assembly bicameral in December, 1790; the Senate of Pennsylvania sat in the room on the second floor which extended across the entire eastern end of the building; and apparently the Governor and the Secretary of the Commonwealth occupied the remainder of the second floor.[172] Thus surrounded was the Supreme Court's

the State Assembly were to be moved out. The doorkeeper, however, had a room in the building for more than five years longer. (Jour. of Sen. of Pa., VI, 41, 77, 91, 93; Jour. of House, 1795/6, pp. 96, 105, 114, 142, 188, 189, 452.)—If the Senate Chamber was smaller than that of the House the Senate had room for other activities on its floor of Congress Hall.

[170] The house was rented from Robert Morris and was separated by an open space from what was then Morris's own residence at the southeast corner of Sixth and Market. The house was located and described in Richard Rush, *Occasional Productions*, 32, 93; correspondence between Washington and Lear in September to November, 1790, in Ford's edition of Washington's writings and in the manuscript division of the Library of Congress. It is shown in Watson, *Annals of Philadelphia*, 1830 ed., facing p. 361. Morris had occupied this house: White's Philadelphia Directory, 1785, p. 48. Biddle's Directory, 1791, pp. 148, 92, locates Washington at 190 High Street and Morris at 192. The street had been popularly known as Market Street for half a century: note 74.

[171] The time of opening the Court is not shown in its Minutes nor in the Burd Papers. The Journals of the Pennsylvania House and Senate show that on Feb. 7 the House met at 3 P.M. and the Senate for a short session at 10 A.M. The next day both Houses met at 10 A.M.

[172] They succeeded to the Council and its secretary. There is nothing to indicate that the Council had moved from its room at the southwestern corner of the second floor before the constitution of 1790 became effective, although we may read of such things as the spending of £577 for a writing desk for the Council (Journals, I, 631, for Feb. 9, 1780); the providing of nails and green cloth for a table in the council chamber and the setting up of a stove (Minutes of Assembly, 1789/90, p. 63; Minutes of Sup. Ex. Coun., Pa. Col. Rec., XV, 598; see also Journals, I, 636); the purchase of books and of covers for globes and the framing of pictures. (Pa. Col. Rec., XIV, 10, 244, 265, 479, 587; XV, 138; see also XVI, 358; *Pennsylvania Packet*, Jan. 28, 1789.) A message from the President and Council to the Assembly on Feb. 9, 1790 (Minutes of Assembly, 1789/90, p. 119) said that the books and records of the secretary of the Council were deposited in the State House. They were probably in or near the council chamber,

entrance upon the ten years in which the governments of the Nation and the State were to be centred in this small group of buildings.

To the east of the State House, its committee-room and its eastern wing the City of Philadelphia was then constructing a City Hall.[173] South of the Hall and close to it was the building of the American Philosophical Society, then two stories high. Most of its rooms were rented to the University

although the message as a whole referred to both the main building and its wings as the State House. By the constitution of 1790 the functions of the President and Council were transferred to the Governor and he was authorized (Art. II, sec. 15) to appoint a secretary who should "keep a fair register of all the official acts and proceedings of the Governor." Governor Mifflin appointed A. J. Dallas to this position early in 1791. (G. M. Dallas, *Life and Writings of A. J. Dallas*, 22.) City directories, when they dealt with the matter, said that Dallas's office was in the State House, and Hardie, Philadelphia Directory, 1793, p. 178, said that it was on the second floor. By the Act of April 3, 1791, the Governor was authorized to appoint a suitable person to take care of the State House. In February, 1798 (Sen. Jour., VIII, 154), the Governor replied to the Senate that he would like to be able to supply to it for use as a committee room one of the rooms "in which the business of the Executive Department is at present transacted; but I find that it would be impracticable to discharge the more important and confidential duties that arise, in the same apartment with the clerks, and exposed constantly to interruptions from the miscellaneous applications of the citizens." This shows that full use was then being made of the second floor. Of course, not all of the offices of the State were in the State House or its eastern wing. Appendices to city directories show that offices of the state government and of the federal government were scattered over the city. (See, *e.g.*, White, 1785, p. 91; Biddle, 1791, pp. 150–168.) We cannot give attention to the various changes which had been made in the use of the State House or to shifts in the location of the state offices (see, *e.g.*, *Diary of Jacob Hiltzheimer*, 72; Minutes of Sup. Ex. Coun. for Nov. 23, 1789, and Oct. 7, Nov. 10, 1790; House Jour., Jan. 25, 1791, p. 116), but we may note that in February, 1790 (Minutes of Assembly, 1789–90, p. 119) the Governor and Council suggested to the Assembly "that the erecting of a building as a repository for all public records, in which the several officers whom we have mentioned may be accommodated for the transaction of their respective duties, will be a matter of public utility" (see also p. 124 and House Jour., 1794–5, pp. 10, 19, 22, 24); that it was proposed to erect such buildings adjoining the south side of the wings of the State House; and, years later, proposed to use for such purpose the building which had been erected by the State on the west side of Ninth Street below Market for the use of the President of the United States; but that nothing came of these plans nor of the proposal made in 1793 for the erection of "an additional building adjoining the west end of the State House, upon a plan as nearly similar as may be to the building now used as a committee-room for the House of Representatives, to be appropriated for the accommodation of the Judges of the Supreme Court of this commonwealth and for the keeping of such books and papers as they may order and direct." (Sen. Jour., V, 153, 171, 172, 234, 245, 258, 267, 270; VIII, 14; House Jour., 1792–3, pp. 50, 277, 342, 343, 345; *Dunlap's American Daily Advertiser*, March 23, 1793, p. 3.) For offices of the United States in the Revolutionary period see Sanders, *Evolution of Executive Departments of the Continental Congress*, 22, 54, 63, 64, 73, 111, 153.

[173] Note 198.

of the State of Pennsylvania, whose students were summoned to their classes, when the Assembly was not in session, by the ringing of the State House bell.[174] There were no buildings upon the remainder of the walled-in State House yard.[175]

The federal capital had been moved to the most populous region in the country. Some forty-two thousand persons were living in a district extending about two miles along the Delaware River and scarcely more than half a mile from its bank;[176] and this centre of civilization had many places of interest to thoughtful men. Across the street from the Philosophical Society was the new building of the Library Company of Philadelphia, to be its home for the next ninety years.[177] Hardly more than a block east of it was Carpenter's

[174] Note 149.

[175] On the wall see note 116.

[176] The census of 1790 showed only 28,522 persons in the region between Vine and Cedar (South) Streets against 32,305 in the city of New York; but there were 9907 north of Vine in Northern Liberties and 5663 south of Cedar in Southwark. (*A Century of Population Growth*—published by Census Bureau—pp. 194, 197.) Biddle, Philadelphia Directory, 1791, p ix, said that Philadelphia and its suburbs, including Southwark and the compactly built part of Northern Liberties, had a population of 42,400. Biddle had had charge of the census in Pennsylvania. (*Universal Asylum and Columbian Magazine*, VI, 329.) On the size and shape of the built-up region see Schoepf, *Travels in the Confederation*, I, 58; Weld, *Travels in North America*, 1st ed., 4; Moreau de Saint-Méry, *Voyage aux États-Unis de l'Amérique*, 280, 299; Barbé-Marbois, *Our Revolutionary Forefathers*, 128; *Journals of Manasseh Cutler*, I, 257; *Pennsylvania Gazette*, July 13, 1785, p. 3, col. 1; Jones, *Life of Ashbel Green*, 156. A correspondent to the *Pennsylvania Gazette* for Sept. 1, 1790, proposed meeting the need of the Federal Government for buildings by erecting them at Centre Square. "To erect the buildings there will, in one year, raise a town, which perhaps fifty years without it, will not accomplish. . . . Let a city be erected west of Broad Street."—On the large German element see Kalm, *Travels in North America*, I, 29, 56, 58, 388; Moreau de Saint-Méry, 280, 285, 322, 323; Weld, 68; *A Century of Population Growth*, 116; 59 Pa. Mag. Hist. and Biog. 433; Turner, *The Frontier in American History*, 100, 109; Dunaway, *History of Pennsylvania*, 78–83. For a criticism of the German spoken, see Schoepf, I, 107. Some students at the University were taught "the learned languages through the medium of the German tongue." (Act of Sept. 22, 1785, secs. 7, 8.) When the Federal Constitution was proposed, the State circulated copies of it in German as well as in English. (Minutes of Assembly, Sept. 29, 1787.) The Minutes of the General Assembly were printed in both languages. (See, *e.g.*, Minutes, Oct. 28, 1786; Nov. 9, 1789; Sen. Jour., V, 9, 21, 24; House Jour., Dec. 5, 1793; April 22, 1794; Dec. 3, 1795.) On printing an election law in both languages see Sen. Jour., IX, 174.

[177] Note 113. It is shown in Birch, *Views of Philadelphia*, Library and Surgeons Hall. On the library see Schoepf, *Travels in the Confederation*, I, 86; Biddle, Philadelphia Directory, 1791, p. xi; *Freeman's Journal*, April 11, 1792; Moreau de Saint-Méry, *Voyage aux États-Unis de l'Amérique*, 379; Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 130; Stephens, Philadelphia Directory, 1796, appendix, pp. 45, 47. The freedom of the library was conferred on the President and Congress. (*Dunlap's American Daily Advertiser*, Jan. 20, 1791; *Gazette of the United States*, Jan. 22.)

Hall, where the first Continental Congress had met.[178] The old Court House was at Second and Market.[179] The house in which Franklin had lived was nearby.[180] Peale's Museum was at Third and Lombard, with a splendid gallery of portraits and a growing collection of specimens of natural history.[181] And there was the house on Market Street in which Washington lived and in which Jefferson and Hamilton were then fighting the first skirmishes of battles which were to be taken to the country.[182] But none of these places,

[178] Note 65.

[179] Note 21. Two generations after the State House had become the capitol of Pennsylvania governors were still proclaimed at the Court House. (Sen Jour, IV, 34; VII, 29–36, 42; see also Schoepf, *Travels in the Confederation*, I, 59; *Pennsylvania Gazette*, Nov. 12, 1785; Dec. 19, 1787.) East and west of the Court House was a food market which was one of the best in the world. (Schoepf, 112; *Journals of Manasseh Cutler*, I, 271; Brissot de Warville, *New Travels in the United States*, 243; Jedediah Morse, *American Geography*. Stephens, Philadelphia Directory, 1796, appendix, 68; La Rochefoucauld-Liancourt, *Voyage dans les États-Unis*, VI, 318.) Several pages in Birch, *Views of Philadelphia*, are devoted to the market.

[180] It was near Market Street between Second and Third. (*Journals of Manasseh Cutler*, I, 267.) Franklin had been gathered to his fathers (*Pennsylvania Gazette*, April 21, 28, 1790) but his library might still be seen by visitors. (Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 155. See also Cutler, I, 269. Compare advertisement of sale of a great part of the library in *Philadelphia Gazette*, Feb. 22, 1803.)

[181] *Freeman's Journal*, Oct. 13, 1784, p. 3, col. 3; Aug. 20, 1788; July 7, 1790; *Journal of Manasseh Cutler*, I, 259; *Diary of Francisco Miranda*, 29; Schoepf, *Travels in the Confederation*, I, 89; *Poulson's American Daily Advertiser*, July 17, 1828, p. 2, col. 4; *Pennsylvania Packet*, Feb. 8, 1790; Hardie, Philadelphia Directory, 1793, 212; 1794, 230; Wansey, *Journal of an Excursion to the United States*, 1st ed., 134. In *Dunlap's American Daily Advertiser* for Feb. 8, 1791—the second day on which the Supreme Court sat in the State House—in order to enlarge his museum he advertised the sale of a machine which showed "six moving pictures, or transparent perspecctive views, with changeable effects, with which the public was entertained for more than two years."

[182] Note 170.—On the College of Philadelphia, at the southwest corner of Fourth and Arch, larger than the University and soon to be consolidated with it, see note 149; Schoepf, *Travels in the Confederation*, I, 73; Moreau de Saint-Méry, *Voyage aux États-Unis de l'Amérique*, 384; Graydon, *Memoirs*, 35; Duché, *Observations*, 15.—On the Pennsylvania Hospital in Pine Street near Seventh, see Birch, *Views of Philadelphia*; *Journals of Manasseh Cutler*, I, 270; Weid, *Travels in North America*, 1st ed., 4; La Rochefoucauld-Liancourt, *Voyage dans les États-Unis*, VI, 315.—On the jail, which Jedediah Morse, *American Geography*, called the neatest and most secure building of the kind in America, see Birch, *Views*, Goal in Walnut Street; Cutler, I, 263; *Pennsylvania Gazette* and *Federal Gazette* for March 18, 1789; Wansey, *Journal of an Excursion to the United States*, 1st ed., 157; Weid, 7. La Rochefoucauld-Liancourt, VI, 314, said, "Ses prisons, dont j'ai déjà beaucoup parlé, sont le seul établissement public à Philadelphie, et même dans toute l'Amérique, qui soit supérieur à ceux de la même espèce que l'on voit en France ou en Angleterre."—On Philadelphia streets see Notes,

PLATE 8

THE CITY HALL, PHILADELPHIA

Photographed in 1922, during the restoration of the interior. To the left is the home of the American Philosophical Society, the attic story of which dates from late in the 19th century.

interesting as they were, could compare in importance with the buildings on the State House Square, where so much history had been made during the past sixty years and where so much was yet to be made during the next ten years.

It is unnecessary to recount the events which made the State House famous. Before leaving the building, however, it may be interesting to note three features of the government which had been carried on from this capitol. (1) In the first half of the eighteenth century a part of the revenues of the Province was secured by issuing paper money and loaning it at interest. The State House was built on such interest and other expenditures were met in that way.[183] But the issuance of paper money was closely limited for many years.[184] (2) In colonial days the right to vote was restricted [185] and the back country was not allowed fair representation.[186] These grievances were redressed during the Revolution [187] but even afterwards the southeast so treated the west [188] that

V, 489; Schoepf, I, 58; Brissot de Warville, *New Travels in the United States*, 314; *Pennsylvania Gazette*, Feb. 24, 1790; *Federal Gazette*, March 20, 1790; Moreau de Saint-Méry, 280; Biddle, Philadelphia Directory, 1791, iv; *Pennsylvania Gazette*, June 29, 1791; Act of Sept. 13, 1791.—John Fitch, "owner of the steamboat" (Biddle, Philadelphia Directory, 1791), who was then living in Philadelphia, had carried passengers on a number of steamboat excursions from Arch Street wharf to Chester, to Wilmington and to Burlington in the previous summer (*Gazette of the United States*, May 15, 1790, p. 3, col. 3; *New York Magazine*, August, 1790, p 493; *Federal Gazette*, July 30, 31, Aug. 11, 12, 18, 28, Sept. 10; *Pennsylvania Packet*, Aug. 12, Sept. 11; Thomas Boyd, *Poor John Fitch*, 169–252.)

183 Note 82; Votes, III, 427; IV, 40, 604, 605, 613, 690; V, 450; VI, 156, 161, 194.

184 The Assembly was restrained by the governor under orders from England. (See, *e.g.*, Votes, IV, 218; V, 448, 450; VI, 194; and, in *Col. Univ Studies*, Shepherd, "The History of Proprietary Government in Pennsylvania," 401.) In 1769 a bill of exchange for £ 500 sterling cost only £ 787-10-0 in Pennsylvania money. (Votes, VI, 191.) In 1780 the salary of the chief justice went to £ 12,000 per quarter. (Jour. of House of Rep., I, 648.) By June, 1781, the rate of exchange for specie was 75 to 1. (Journal, I, 660.) See also *Diary of Jacob Hiltzheimer*, 72, 73; Bezanson, Gray and Hussey, *Prices in Colonial Pennsylvania*, 431, 432.

185 "An act to ascertain the number of members of Assembly and to regulate the elections," passed Jan. 12, 1705/6. See also Lincoln, *The Revolutionary Movement in Pennsylvania*, 40–52, 80, 96.

186 See Gouverneur Morris in Federal Constitutional Convention, July 11, 1787; Shepherd, *The History of Proprietary Government in Pennsylvania*, 546; Lincoln, "Representation in the Pennsylvania Assembly Prior to the Revolution," 23 Pa. Mag. Hist. and Biog. 23; Turner, *The Frontier in American History*, 112.

187 Act of March 23, 1776 (Votes, VI, 688, 693, 698; Acts of Com. of Pa., 1775–1781, appendix, c. II); Constitution of 1776, frame of government, secs. 6, 17.

188 *Autobiography of Charles Biddle*, 197, 217–219; McMaster and Stone, *Pennsylvania and the Federal Constitution*, 14, 15, 69; Min. Sup. Ex. Coun., XV, 286, 317, 408; House Jour., March 2, 1793; *Aurora*, April 5, 1799, p. 2, col. 2.

when the east lost political control the capital was taken away from it and moved inland.[189] (3) Before 1750 it was repeatedly the case that the same man was speaker of the Assembly and chief justice of the supreme court;[190] and William Allen, who was chief justice from 1750 to 1774, was a member of the Assembly from 1756.[191] The constitution of 1776 sought to prevent dual office-holding,[192] yet Chief Justice McKean of Pennsylvania was also a member of the Continental Congress from Delaware and was for a while president of the Congress.[193] The views as to the holding of

[189] Act of April 3, 1799. There were repeated epidemics of yellow fever in Philadelphia in the seventeen nineties (see, e.g., Burd Papers, 182, 184, 192, 198) but efforts to move the capital from Philadelphia began before the first of these epidemics. (See Minutes of General Assembly, April 8, 1782; Feb. 7, 1784; March 3, 1787; *Pennsylvania Gazette*, March 7, 1787.) Turner, *The Frontier in American History*, 120, 121, points out that "the interior region from New England to Georgia, had a common grievance against the coast; that it was deprived throughout most of the region of its due share of representation, and neglected and oppressed in local government in large portions of the section. The familiar struggle of West against East, of democracy against privileged classes, was exhibited along the entire line." He calls attention to the actions of Virginia, South Carolina, North Carolina, New York and Pennsylvania, between 1779 and 1799, transferring the capitals from the coast to the back country.—By the act of 1799 the removal was to Lancaster "until the permanent seat of government shall be hereafter established." Jedediah Morse, *American Geography*, said, "The borough of Lancaster is the largest inland town in the United States."

[190] David Lloyd was speaker from 1723 to 1724 and from 1725 to 1729 and was chief justice from 1718 to 1731. John Kinsey was speaker from 1739 to 1750 and chief justice from 1743 to 1750. At times while he was chief justice each of these speakers was paid for drafting bills; Votes, II, 402; III, 35; IV, 47, 115. James Logan, the chief justice from 1731 to 1736, was a member of the Provincial Council throughout that period. On these three men see also Sharpless, Political Leaders of Provincial Pennsylvania. The justices were commissioned by the governors (Act of May 22, 1722) while the speakers were elected by the Assemblies. The dual office-holding was, therefore, not analogous to that of the lord high chancellor in England. Compare Holdsworth, *Some Lessons from Our Legal History*, 37.—All three justices of the Supreme Court in 1716 were also members of the Assembly: Votes, II, 193, 194. On multiple office-holding in Massachusetts see account of Thomas Hutchinson in *Dictionary of American Biography*.

[191] See Votes from October, 1756; Smyth, *Life and Writings of Benjamin Franklin*, IV, 282, 332, 270.

[192] Frame of government, sec. 23.

[193] McKean, who was then a member of Congress from Delaware, became chief justice of the supreme court of Pennsylvania on Sept. 1, 1777. (Pa. Archives, V, 621.) Two days later he published in the *Pennsylvania Journal* an address to the electors of Newcastle county, Delaware, saying that for nearly seventeen years they had elected him to the Delaware General Assembly although for the last five years he had resided out of that state, but that it was now absolutely impracticable for him to serve longer in that capacity. On Feb. 24, 1779, the Pennsylvania Assembly resolved that a judge of the supreme court of Pennsylvania could not consistently with the state constitution

incongruous offices which prevail at the present time did not govern provincial Pennsylvania. Their acceptance was gradual.

But we must now turn from those who used the State House and from the State House itself to consider another building which was under construction when Chief Justice Jay and his associates were sitting in the old courtroom of the highest court of Pennsylvania.

The Philadelphia City Hall

The third home of the Supreme Court was in the City Hall which was at the northeast corner of the State House Square on the site which had been set apart for just such a building in 1736.[194] Into this courtroom the justices entered on the first of August, 1791;[195] here they sat for a term of three days[196] and here was their home for the next nine years.[197]

The City Hall was a new building. Its construction began in the previous summer[198] and a part of its cost was met by a lottery which was advertised in the Philadelphia newspapers throughout the winter.[199] It was not ready for occupancy until the summer of 1791 was well advanced. The June session of the Mayor's Court, opening on the twentieth of

sit in the Congress as a delegate of another state· Jour. of House of Rep. of Com., I, 321. Evidently he did not so interpret the constitution, for he continued to hold both positions. The Assembly did not further challenge his stand. A year later it increased his salary as chief justice because of changing conditions, and it granted a further increase in the following winter. (Feb. 20, 1780: Jour., I, 433, 451; Dec. 23, 1780: I, 564. See also Dec. 20, 1780: I, 559.) On July 10, 1781, he was chosen president of the Congress. (Journals of Continental Congress, XX, 733; Pa. Archives, IX, 267.)

[194] Note 117.

[195] *Dunlap's American Daily Advertiser*, *Freeman's Journal*, *Gazette of the United States* and *Pennsylvania Gazette* for Aug. 3, 1791; *Daily Advertiser*, New York, Aug. 5; *Boston Gazette*, Aug. 15.

[196] Minutes of the Court.

[197] The Minutes of the Court from February, 1792, to August, 1799, usually said that it sat in the City Hall. The Minutes for 1800 cannot be located, but Philadelphia papers for August, 1800, told of its term in that city. (*Claypoole's American Daily Advertiser*, Aug. 12, 14; *Philadelphia Gazette*, Aug. 12. See also *Philadelphia Gazette*, Feb. 3.)

[198] Pa. Col. Rec., XVI, 410; *Pennsylvania Gazette*, Sept. 1, 1790, p. 2, col. 3.

[199] Note 246.

that month, was held in the State House,[200] although presumably it would have been held in the City Hall if the courtroom there had been available; and, on the other hand, the Supreme Court of the United States made use of the City Hall hardly more than a month later.

Apparently both courts had the same courtroom, in the southern part of the first floor. The Mayor's Court sat there,[201] and there held jury trials.[202] That court was the most important non-federal court which met in the building.[203] Therefore it doubtless had the room which was most suitable for use as a courtroom, especially since, as it sat only four short terms each year,[204] its room could have been available to other courts for many weeks at a time. The federal

[200] See the sheriff's proclamation published in *Dunlap's American Daily Advertiser*. On June 8, 9, 10, 1791, it said that the court would sit on June 20 but did not say where. Perhaps at first there was some thought that the room in the City Hall might be usable. But later notices—June 11, 13, 14, 16, 18, 20—said that the court would be held at the State House.

[201] Mease, *A Picture of Philadelphia*, 325, says, "In the latter house, the mayor's office and mayor's court are held, on the first floor; the city councils and city commissioners sit up stairs." The book was published in 1811, but there had been no change in local government between 1791 and 1811 which made change in housing necessary. The main entrance to the building was on Chestnut Street. The southern end was, therefore, the proper location for a large room. It could there extend across the entire breadth of the building. On the mayor's court see notes 202, 203.

[202] See Act of March 11, 1789, sec. 20, for its criminal jurisdiction.

[203] It was created by Act of March 11, 1789, sec. 20. Minor courts were created by the same act. Whatever jurisdictional changes may have been made after the court entered upon the use of its room, the sheriff's notices in the newspapers cited in this note and in note 228, show that the mayor's court continued active while the Federal Government was in Philadelphia. See also Stephens, Directory, 1796, 226, 227 and appendix, p. 8; Stafford, Directory, 1798, p. 29; 1799, p. 28; Mease, *A Picture of Philadelphia*, 102. So far as appears, no state or county court was held in the City Hall between 1791 and 1821. State courts sat in the State House after the building of the City Hall, note 64. Courts of oyer and terminer were held in the State House. (*Aurora General Advertiser*, Sept. 14, 18, 1795; March 1, 1796; *Claypoole's American Daily Advertiser*, March 3, 1796; *Aurora General Advertiser* and *Philadelphia Gazette* for Feb. 3, 1800.)—Stephens, Directory, 1796, appendix, 68, said that the State House contained the hall in which the supreme court was held. The paragraph was worded carelessly but it is entitled to fully as much weight as the traveler's casual reference to the supreme court of the state in Weld, *Travels through the States of North America*, 1st ed. (1799), 6, where it is said that, "In the city hall the courts of justice are held, the supreme court of the United States, as well as that of the state of Pennsylvania, and those of the city." Yet see Moreau de Saint-Méry, *Voyage aux États-Unis de l'Amérique*, 375.

[204] Note 203. It will be remembered that at this time there were less than 30,000 persons within the political limits of Philadelphia: note 176.

courts doubtless preferred to use its accommodations.[205] While the Minutes of the Supreme Court tell us year after year that its sessions were held in the City Hall, they tell us only once what room in that building was used; but that one entry in the Court's records was made under such circumstances as to point to the Supreme Court's customary use of the room of the Mayor's Court.

According to the Minutes, on Saturday, March 12, 1796, the Supreme Court "adjourned till Monday morning next at ten o'clock." On Monday, "Pursuant to adjournment the Court met this morning in the Common Council Room of the Corporation of Philadelphia." That room was up stairs.[206] The day was the last day of a session which had continued two weeks longer than any previous one.[207] Twelve days before, when it may have been thought that the work of the federal court was approaching its end, Monday, the fourteenth day of March, at ten o'clock in the forenoon had been selected as the time for holding the Mayor's Court, "of which all constables and persons bound by recognizance to appear thereat are to take notice and govern themselves accordingly," and the sheriff had published such notices in the papers throughout the intervening days.[208] Under such circumstances, on that Monday morning the Supreme Court finished the little business which remained before it in the Common Council Room and special note was made of that fact.

The small Court House which was built at Second and Market Streets in 1710[209] served as Philadelphia's city hall for eighty-one years, for the local government constituted

[205] The Supreme Court later held several jury trials in the building: note 256. On lower federal courts there in August, 1791, see Minutes of Supreme Court, Aug. 3; *Daily Advertiser* (New York) Aug. 12, 18, 22; *Argus* (Boston), *Freeman's Journal*, *Gazette of United States* and *Pennsylvania Gazette* for Aug. 17; *Dunlap's American Daily Advertiser*, Aug. 16, 20; *Virginia Herald*, Aug 25, Sept. 1.

[206] Note 201.

[207] Minutes of the Supreme Court.

[208] See, *e.g.*, *Claypoole's American Daily Advertiser*, March 3, 1796; *Aurora General Advertiser*, March 4, 5, 7; *Independent Gazette*, March 12.

[209] On the building see note 21. In Heap's East Prospect of Philadelphia, 1753, in Jefferys, *Topography of North America*, 1768, the building is called both Court House and Town House. It was not devoted simply to judicial uses: note 21 and *Diary of Jacob Hiltzheimer*, 59, 61, 63, 73, 86, 88, 102.

by Penn in 1701 was neither strong nor popular, that government was abolished at the Revolution and a new one was not established until March, 1789, so that while a more modern building was long desired [210] no active steps towards its construction were taken until shortly before the Federal Government moved to Philadelphia.

The charter of 1701 was granted by Penn as proprietary and governor, without the coöperation of the Assembly.[211] By it, under the title of "Mayor and Commonalty of Philadelphia," a small self-perpetuating group of men was empowered to pass ordinances,[212] conduct hearings in all criminal cases and try and punish minor offences,[213] but it was not authorized to tax. Its only revenues were from fines for minor offences,[214] fines for refusal to accept public office [215] or

[210] Notes 117, 231.

[211] The charter is printed in Charters and Acts of Assembly of Province of Pennsylvania (1762), 10–14. See also Minutes of Common Council of Philadelphia, 1704–1776, 65, 73, 74; Votes of Assembly, II, 49, 50; Charters etc. 49, 52.

[212] For instances see Minutes of Common Council, 59, 80, 164, 172, 271, 280, 299, 314–316, 373, 696. In 1722 (p. 222) it ordered that "no person, butcher or others, be suffered to smoke tobacco in the market or market house, or in or at any stalls, under the penalty of one shilling for every offence, as the same is inflicted by an act of Assembly of this province, now in force against smoking in the streets." The law referred to was passed in 1701. Charters etc. 15. In 1749 there was a resolution against actors: Minutes, 523.

[213] In addition to the charter see Minutes, 27.

[214] By the charter it had this power "without being accountable to me or my heirs for any fines or amercements to be imposed for the said offences or any of them." The Minutes contain many entries on remission of fines.

[215] The charter gave authority to fine "so as the mayor's fine exceed not forty pounds, the alderman's five-and-thirty pounds, and common-council-men twenty pounds, and other officers proportionably." See, *e. g.*, Minutes, 448, for Oct. 1, 1745: "Alexander Taylor refusing to serve the office of mayor of this city, he is fined the sum of thirty pounds and then the board proceeded to a new election and chose Joseph Turner by a majority of votes, who having refused to execute the said office was fined the sum of thirty pounds, and then the board proceeded to a new election and Alderman Hamilton was elected by a majority of votes." In 1758 and again in 1762 two men each time refused to serve as mayor. They were fined forty pounds each. (Pp. 633, 634, 677. See also 6, 42, 97, 138, 218, 672.)—By the act of 1705 "to ascertain the number of members of Assembly and to regulate the elections" if one who was elected representative did not serve he might be fined unless excused by the Assembly. (Charters etc., 17, 2, 28, 29.) Such a fine was imposed. (Votes, II, 145; see also 199.) By other acts of the same year (Charters, 42, 34) a person appointed overseer of the poor might be fined five pounds if he refused to serve and a heavier penalty if he neglected to bring in the name of a suitable successor; and justices and freeholders neglecting or delaying to do their duty in the trial of negroes were also subject to fine. (See also Act of March 9, 1771, as to overseers.) For Massachusetts see Laws and

for tardiness of members of the Common Council in attending its meetings,[216] fees for grants of the freedom of the city,[217] charges for the use of city property [218] and donations.[219] From time to time, as the growing city required greater municipal power, the Assembly established boards and assessors, authorized them to look after the streets, police, fire protection and the poor and gave them power to tax and regulate in coöperation with the Council,[220] but no independent power of taxation was ever granted to the government established by the charter.[221]

The increase in population, however, brought greater revenues, so that while the income of the Mayor and Commonalty was small at the beginning of the century, before 1775 the corporation was receiving considerable returns from rental of space in the Court House and markets which it had built in the middle of the main street,[222] from the middle ferry

Liberties of Massachusetts, 1648, title Freemen; for Virginia see Hening, I, 350; II, 69, 70, 384, 107, 205; for medieval England see Pollard, *Factors in Modern History*, 3d ed., 28, 301; Pollard, *Evolution of Parliament*, 2d ed., 101, 102, 109, 154; Palgrave, *Collected Historical Works*, VIII, 37 and ix; Porritt, *The Unreformed House of Commons*, c. 12; for earlier times see Dill, *Roman Society in the Last Century of the Western Empire*, 2d ed., 251, 252, 256.

216 Minutes, 24, 59, 60, 62, 166.

217 By the charter the status of freeman or freewoman might be attained by possessing specified qualifications or by purchase. See Minutes, 34, 271. There were many instances of purchase, at varying prices. (Minutes, 16, 21, 25, 117–135, 166, 186.)

218 Minutes, 20, 79, 103, 105, 109, 174, 443, 446, 475, 476, 563, 767, 776, 780; see also note 222. The corporation even leased the potter's field for use as a pasture. (Minutes, 622–625, 661, 687, 711.)

219 It had been customary for the mayor at the end of his term to give a dinner to the Council: Minutes, 234, 463. In 1746 Mayor Hamilton in lieu thereof presented £ 150 to the corporation towards the building of an exchange or other public building: 463, 464. Later mayors made donations: 502, 511, 563; cf. 533. These sums, with interest, amounted to £ 834 in 1760: 663, 616. In June, 1763, £ 500 of this special fund was voted towards erecting an exchange at the Front Street end of the Jersey market: 684; cf. 690. The next report on this fund was in October, 1772: 776. At that time there remained in the treasurer's hands on account of building an exchange or some public edifice £ 136-15-1.

220 Acts of June 7, 1712; Aug. 19, 1749; Feb. 9, 1750/51; Sept. 15, 1756; Jan. 18, 1757; March 26, 1762; Feb. 7, 1766; March 9, 1771; Minutes of Common Council, 296, 297, 368, 409, 411, 412; compare Minutes, 22, 231, 396, 747, 759, 774.

221 An act of 1705, Charters, 39, 41, went so far as to empower the Council to appoint overseers of the poor who might tax. See also Minutes of Council, 80

222 Minutes, 57, 69, 74, 93, 148, 149, 177, 187, 475, 476, 608, 644, 767. On the Jersey market see 295, 395, 433, 459, 684. In 1773, on recommendation of the Assembly that additional markets be provided, the corporation undertook to build a market in the middle of Market Street between Third and Fourth, but desisted because of the forcible resistance of persons living in the neighborhood. (Minutes, 778–788.) On revenues towards the end of the century see La Rochefoucauld-Liancourt, *Voyage dans les États-Unis*, VI, 321.

over the Schuylkill River,[223] from interest on money loaned out [224] and presumably from fines.[225] Expensive dinners were given in honor of newly-arrived governors,[226] salaries were paid [227] and grants were made towards improving the channel of the Delaware River,[228] towards making a road from the middle ferry into Lancaster County [229] and for other public purposes.[230] In the spring of 1775 plans for the building of a city hall were being considered.[231]

Those plans did not materialize because after the overthrow of the proprietary government the Assembly declared that "all powers and jurisdictions not founded on the authority of the people only have become null and void." By that and other acts the powers of the corporation were distributed between the Supreme Executive Council, the justices of the peace of the city, the wardens and the street commissioners, who exercised them until 1789.[232]

But the site for a city hall had been bought [233] and in December, 1784, the President of the State and Council informed the Assembly that they had in their possession "bonds and mortgages lately belonging to the corporation of the city, to the amount of near fifteen hundred pounds, exclusive of interest for several years." [234] The Assembly authorized the wardens of the city to collect all interest due on such funds and with such other funds as might be in their hands con-

[223] Minutes, 675, 764, 766, 802; compare 211, 214, 435, 548, 739, 740.

[224] *E g*, Minutes, 545, 663, 770.

[225] With Minutes, 628, 659, 759, compare 520, 768, 776.

[226] Minutes, 320, 334, 599, 653, 695, 777, see also 101, 723.

[227] Minutes, 108, 110, 477, 480, 511, 533, 666, 677, 682. There were profits connected with the office of mayor the nature of which is not disclosed in the Minutes: see 510, 511, 666 The city treasurers were paid commissions. They did not always make prompt collections from some persons: 607 et seq. See also 173, 174

[228] Minutes, 774.

[229] Minutes, 774.

[230] Net revenues from wharves were devoted to repairs of the streets. (Minutes, 672; compare 712. See also 529, 584, 759

[231] Minutes, 804, 806, 807. See also note 219.

[232] Act of March 21, 1777. See also Ordinance of Constitutional Convention, Sept. 3, 1776, Jour of House of Rep of Com., I. 73; Acts of Jan. 28, 1777, sec. 5; March 14 and 21, 1777; April 5 and Sept 30, 1779; April 8 and Sept. 16, 1785.

[233] Note 118

[234] Pa. Col. Rec. XIV, 285 Not much of this amount came from the funds which had been donated towards the construction of public buildings, note 219.

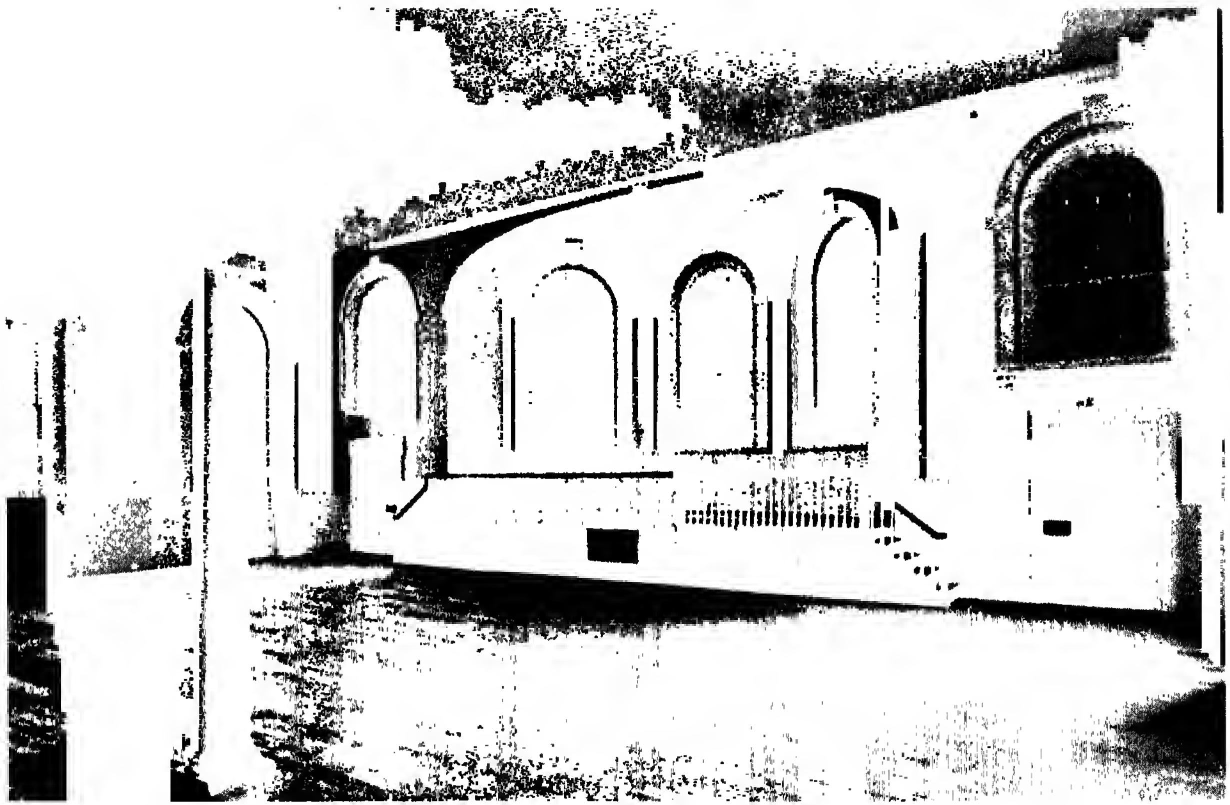

PLATE 9

THE COURTROOM IN THE CITY HALL

As restored. Photographed from under the balcony.

struct a court house at a cost not exceeding three thousand pounds.[235] At least a part of the cost of the building was available.

Nothing was done at once towards the actual construction of the buildings on the northeastern and northwestern corners of the square which had been contemplated for fifty years,[236] but the Assembly directed the city wardens and the county commissioners to submit the plans of their buildings to the approval of the President or Vice President of the State in Council so that the exteriors of the buildings might be alike.[237] The plans were conditioned by the size of the lots—fifty by seventy-three feet [238]—and by the fact that the Assembly had just granted to the American Philosophical Society ground for a building on Fifth Street beginning ninety-six feet south of Chestnut Street.[239] The building line on Chestnut Street was later moved back fifteen feet,[240] leaving eighty-one feet between the new line and the property of the Philosophical Society.

The appearance of the city hall was fixed when one of the alternative plans for the county court house which were presented to the Supreme Executive Council was approved on March 8, 1787,[241] only a few weeks before the construction of the future home of Congress started.[242] By approving that plan the Council decided that the two buildings should each measure approximately fifty by sixty-six feet,[243] with a projecting southern bay reaching from the ground to the roof and that each building should be of brick, two stories in height, with the main entrance on the north, with a marble band

[235] Act of April 8, 1785, secs. 2, 10.
[236] Note 117.
[237] Act of April 8, 1785, sec. 11.
[238] Laws of 1761–2, pp. 170, 171.
[239] Act of March 28, 1785.
[240] Act of March 29, 1787, and Minutes of General Assembly, March 6, 15, 26.
[241] Pa. Col. Rec. XV, 175.
[242] Note 152.
[243] This was the original size of Congress Hall: note 154. Views are cited in that note. It was enlarged in 1793: note 154. Birch, *Views of Philadelphia*, shows the City Hall from the northwest in State House with a View of Chestnut Street and from the southwest in Back of the State House

course under the second story, with a peaked roof and with a cupola in the middle of that roof.[244]

A new city government was authorized on March 11, 1789, and on March 27 the Assembly authorized a lottery to raise ten thousand dollars, of which eight thousand were to go to the City of Philadelphia towards the building of a city hall and two thousand to Dickinson College. There was a minor amendment to the latter act in the following September.[245] Advertisements of the lottery appeared in the summer of the next year; they continued throughout the winter and drawings were made in April and May, 1791.[246] In this way and from funds which the pre-revolutionary Common Council had raised without resort to taxation and from interest on those funds [247] the city paid for its building. In the case of the City Hall, as in the case of the State House,[248] very little of the cost was met by taxation.[249]

[244] See end of note 154.

[245] Act of Sept. 29, 1789. It dealt with the amount of the prizes.

[246] See, *e.g.*, *Pennsylvania Gazette*, July 28, Aug. 4, Nov. 24, 1790; Jan. 5, Feb. 9, 16, April 6, 1791; *Dunlap's American Daily Advertiser*, Feb. 4, 5, 7, March 4, April 19, 1791.—The drawings were at the State House in the Representatives Chamber. They began on April 19 and continued on twenty-one days until May 19 (*Dunlap's American Daily Advertiser*, April 19 to May 20, 1791. See also May 27, p. 2, col. 1; *Maryland Journal*, May 10.)—Some statements in the advertisements (*e.g.*, *Pennsylvania Gazette*, July 28, 1790) seem indefensible. There was, however, truth in the statement made by the *Federal Gazette* for September 22, 1790, in aid of the lottery that "The temporary alterations of the County Hall, while it subjects the judicial department to some inconvenience, renders it necessary that the City Hall should be completed with the utmost expedition."

[247] Notes 234, 235. See also *Federal Gazette*, April 2, 1789.

[248] Notes 82, 183.

[249] Some details as to the money spent on this building can be gathered from other sources (*e.g.*, Davies, *Some Account of the City of Philadelphia*, 1794, pp. 26, 27) and references to money advanced by the city for fitting up the County Court House for use by Congress are found in state legislation. (Act of Sept. 30, 1791; see also House Journal, 1795-6, Report of Register General, p. 17, on payment to city and county commissioners of $5808.13; House Journal, Dec. 31, 1790; 1791-2, appendix, p. 5.) But it is a pity that the minutes of councils, which may have contained information as to finances and possibly as to the internal arrangement of the City Hall are not available. Richard Rush, in his *Occasional Productions*, 39, note, referring to the renting of Morris's house for Washington in the fall of 1790, said, " F. M. Etting, Esq., of Philadelphia, obligingly sent me for perusal some of the original proceedings of the city councils on this subject. They were found, with other Mss., by those who have charge of the State House buildings, and Mr. Etting had the patriotic intention of passing them all over to the Historical Society of Pennsylvania." The Minutes are not at present in the library of the Historical Society.

As already pointed out, the Supreme Court of the United States sat in the building during the first three days of August, 1791. Its courtroom was very probably on the first floor, extending across the southern part of the building. The bench was doubtless on the southern side of the room, with the bay behind it.[250] The Mayor's Court, which would soon sit in that room, had jurisdiction of criminal cases in which the defendants were entitled to trial by jury;[251] lower federal courts would hold criminal trials with juries in the City Hall in that month;[252] and the Supreme Court of the United States had original jurisdiction of controversies in which the parties were entitled to juries and in the next few years would hold several jury trials.[253] It is clear that accommodations for a jury must have been provided before the Supreme Court entered its new home or only a few days later. The justices, however, do not appear to have worn gowns until Friday, February 10, 1792, for no earlier accounts of wearing them have been found[254] and wearing them on that day was referred to in the newspapers as an innovation.[255]

[250] Such would have been the natural position. It is true that in Congress Hall after the enlargement the Speaker sat on the western side of the room and not near the bay: end of note 155. But that was doubtless because members participated in the proceedings from all parts of the floor and, because of the shape of that room, the western side was nearer the centre of activity than was the southern side. Such considerations did not govern the arrangement of the courtroom.

[251] Note 202.

[252] Note 205.

[253] Note 256.

[254] Flanders, *Lives of the Chief Justices*, II, 37, said that Justice Cushing appeared in New York for the first session of the Supreme Court; that he wore his judicial wig on the street; that the wig aroused such interest and comment that he returned to his lodgings and never again wore the professional wig. For this statement he cited a speaker who had said forty-three years later that an unnamed man, then dead, had said that Justice Cushing had said that he once appeared on the streets of New York in a professional wig. At the most, the story does not show that the Justice wore a gown in the courtroom in February, 1790.—On Feb. 2, 1791, Justice Blair wrote to Justice Wilson from Williamsburg a letter which was sold in May, 1913, by Stan V. Henkels, a Philadelphia auctioneer. I have been unable to locate it. Before the auction, however, it was copied by Burton A. Konkle. It contained a postscript in which Justice Blair said, "Probably by this time our gowns may be finished and the judges may appear in them this time. The cost of them ought to be defrayed without delay and on your application to the Treasurer of the United States for what I owe on that account he will, I am sure, pay it on demand. I would give an order for it if I knew the amount."

[255] The *Gazette of the United States* on Saturday, Feb. 11, 1792, noted that on the

The business done by the Supreme Court during its stay in Philadelphia has been described sufficiently by other writers, so that it is hardly necessary to say more than that few cases were presented for decision but that some of them were quite important. During this period it conducted three jury trials[256] and summoned jurors in preparation for similar cases[257] and it twice spent over a week in hearing arguments but announced its decision within a few days.[258]

On one day in the midst of the term of August, 1796, the Court sat in the State House. The Minutes of the Court are careful to say that on all of the other ten days it met in the City Hall and they are equally careful to designate the State House as the place where it sat on Friday, the fifth of the month. A reason for returning to the City Hall on the next day may be found in the fact that a special jury summoned to appear at the City Hall on Monday, the first of August, had been then excused from further attendance until Saturday, the sixth. The Court may have decided that there would be less confusion if it returned to the place at which the jury had been directed to appear. But the reason for meeting in the State House on Friday is not readily ascertainable. Possibly as he presided over the Court Chief Justice Ellsworth wondered why the Judiciary Act had been so framed as to call upon the Court to sit in Philadelphia in

previous day "The judges appeared on the bench in their robes of office." The *Daily Advertiser* (New York) on Feb. 15 said in a passage dated Feb. 10, "A correspondent observes that he was highly pleased today with the appearance of the Judges of the Supreme Court of the United States in their *Robes of Justice*, the elegance, gravity and neatness of which were the subject of remark and approbation with every spectator." The same language appeared in the *Providence Gazette* for Feb. 25.—As shown by the minutes of the Court, Friday, Feb. 10, was the first day of that term on which a quorum of the Justices was present.

[256] *Georgia* v. *Brailsford*, verdict for defendant, 3 Dall. 1; Minutes of Court, Feb. 4-7, 1794; *Oswald* v. *New York*, verdict for $5315, Minutes, Feb. 5, 6, 1795; *Cutting* v. *South Carolina*, verdict for $55,002, Minutes, Aug. 8, 1797.

[257] Minutes of Court, Aug. 5, 1794; Aug. 5, 1795; Aug. 1, 6, 1796; Feb. 6, 1797; Feb. 5, 10, 1798.

[258] In February, 1795, the argument in *Penhallow* v. *Doane's Administrators* lasted seven days and the decision was rendered eight days later; in August, 1795, the argument in *Talbot* v. *Janson* lasted ten days and the decision came in three days. On the other hand, in February, 1796, *Ware* v. *Hylton* was argued for six days but the decision was not announced until twenty-five days had elapsed.

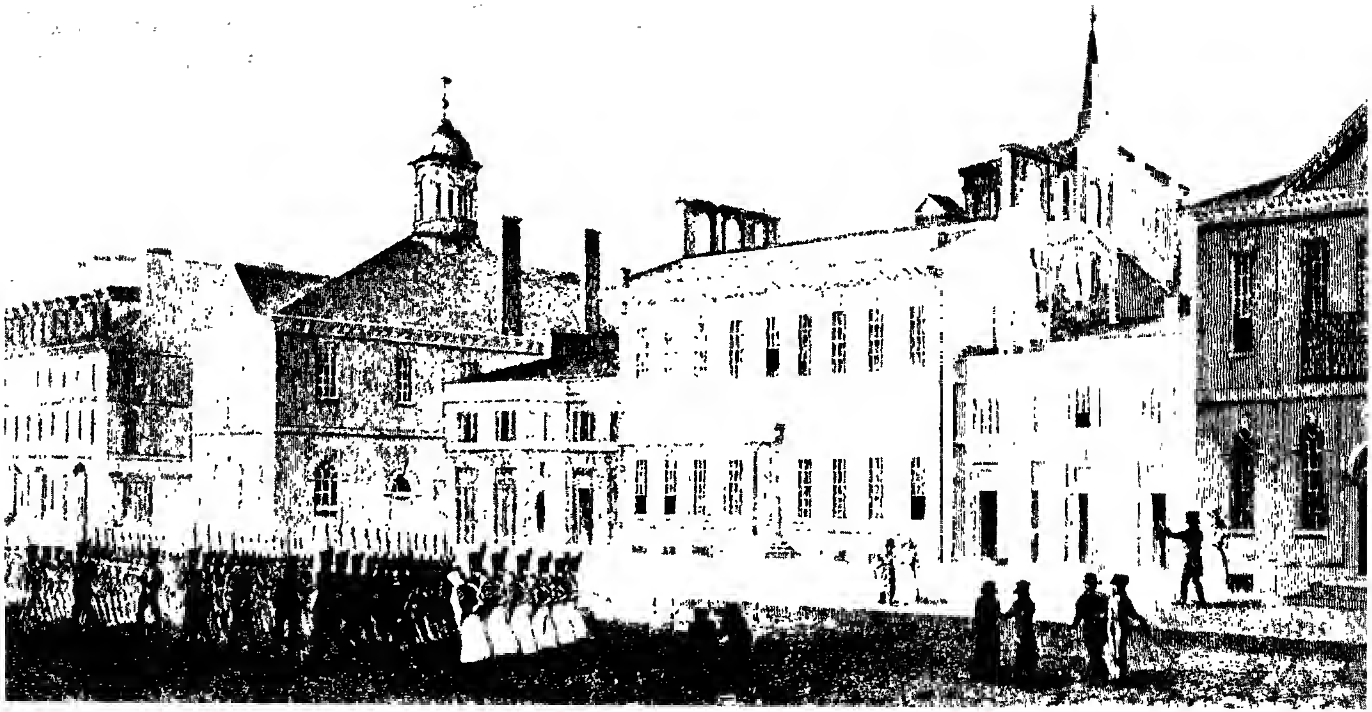

PLATE 10

State House or Hall of Independence

From C. G. Childs, *Views of Philadelphia*, 1830. Engraved in 1828.

August, and he may have suggested that any summer breezes could reach the courtroom in the State House more easily than they could penetrate the room which was so close to the building of the Philosophical Society. Whatever the reason and whatever the experience in the State House, all of the other sessions of the Court in that term were in the City Hall, opening at nine o'clock.

During the years in which the Court sat in Philadelphia the city developed. When the University left the rooms of the Philosophical Society in 1794,[259] Peale moved his museum into its place[260] and the Assembly allowed him to establish a menagerie south of the museum.[261] The population of the city increased forty-five per cent in ten years.[262] The streets were improved[263] and so were the roads which bound Philadelphia to the rest of the state.[264] New buildings were erected,

[259] *Early Proceedings of American Philosophical Society*, 219.

[260] *Early Proceedings*, 222; *Independent Gazetteer*, Oct. 18, 1794; *Claypoole's American Daily Advertiser*, March 8, 1796; La Rochefoucauld-Liancourt, *Voyage dans les États-Unis*, VI, 330; Colton, "Peale's Museum," 75 *Pop Sci. Mon.* 221, 224; Birch, *Views of Philadelphia*, Back of the State House. See also House Jour., 1795/6, p. 68; end of note 142.

[261] Senate Journal IV, 295, 298, 301, Sept. 22, 23, 1794. The joint resolution was "That Mr. Peale be authorized, at his own expense, to erect a palisade fence the breadth of the Philosophical Hall, and extending from the southwest end of it about half a square,—in which may be kept any of the live animals forming part of his collecton,—and the same so to keep during the pleasure of the Legislature or Governor of this commonwealth." Compare end of note 49.—On other places of interest see *Claypoole's American Daily Advertiser*, Feb. 27, March 1, 3, 5, 8, 1796; *Aurora General Advertiser* and *Gazette of the United States*, July 22, 26, 30, 1796; Census Directory, 1811, p. 427; Birch, *Views of Philadelphia*, Congress Hall, showing theatre; and notes 176–182. The city is described appreciatively in La Rochefoucauld-Liancourt, *Voyage dans les États-Unis*, VI, 295, 312–336.

[262] The 1790 census showed 28,522 persons in the region between Vine and Cedar (South) Streets: note 176. The 1800 census showed 41,220 persons in this district. (Report of the Whole Number of Persons within the Several Districts of the United States, 49.)

[263] See end of note 182; Sen. Jour., II, 10; House Jour., 1791/2, 15

[264] For some time £5000 was appropriated annually for the improvement of roads and navigation. (Act of Sept. 28, 1789; House Jour., 1792/3, 51.) Interest in such improvements was organized. (*Diary of Jacob Hiltzheimer*, 166.) On the Lancaster turnpike see Acts of April 9, 1792; April 17, 1795; *National Gazette*, June 7, 1792; on the bridge across the Schuylkill at Market Street, see Act of March 16, 1798; *Poulson's American Daily Advertiser*, Oct. 20, 1800, p. 3, col. 3. More primitive conditions are shown in Wansey, *Journal of an Excursion to the United States in 1794*, 1st ed., 109. He says concerning a bridge over the Neshaminy, on the road to New York, that "two iron chains are strained across the river, parallel to each other, about six

with flat roofs instead of the peaked roofs of earlier times.[265] New nationwide political parties were organized from Philadelphia. The governments of the state and the country were both centered in this city. But its preeminence did not last. Before the century closed both capitals were taken from Philadelphia and State House Square became a place of memories.

Later History of Buildings

We may pass over its later history quickly. In 1802 Peale was granted permission to use most of the State House for his museum.[266] That building and the square were sold to the city in 1816 for seventy thousand dollars,[267] a sum which represented the original cost rather than the value which they then possessed.[268] New buildings were erected on the site of the State House wings and connecting porticos;[269] a new steeple, with clock and bell, was placed on the tower in 1828;[270] and the State House group of buildings was the centre of the governmental activities of Philadelphia until a

feet distance; on it are placed flat planks, fastened to each chain, and on this the horses and carriage pass over. As the horses stepped on the boards, they sunk under the pressure and the water rose between them. No railing on either side, and it really looked very frightful and dangerous."

[265] The growth of population was sufficient to require considerable building. Birch, *Views of Philadelphia*, shows that many of the newer structures had flat roofs. One of them was a house on Ninth Street intended for the use of the President but never occupied by either Washington or Adams. It cost over $70,000 and was a fiasco. (See many references to it in *Diary of Jacob Hiltzheimer*, House Jour. 1795/6, Report of Register General, p. 15; Sen. Jour., VII, 14, 146, 186, 196; Wansey, *Journal of an Excursion to the United States*, 1st ed., 6; Weld, *Travels through America*, 3d ed., 10.) The city had spent £700 on repairing the house on Market Street which Washington occupied. (House Jour., 1791/2, appendix, p. 5.)

[266] Note 141.

[267] Act of March 11, 1816, sec. 5. The corner buildings and the property of the American Philosophical Society were not included: sec. 9. The offer made by this act was accepted by Philadelphia by the ordinance of April 11, 1816.

[268] By the end of December, 1760, £12,260 had been spent on land, State House, tower and wings: note 82. £4000 were afterwards spent on extending the grounds to Walnut Street: note 86.

[269] Desilver, *Map of Philadelphia*, 1819; Wilson, *Picture of Philadelphia*, 1824, p. 319; C. G. Childs, *Views of Philadelphia*, 1830, view of State House, 1828.

[270] *Poulson's American Daily Advertiser*, Feb. 22, March 3, July 4, 1828; Hazard Register of Pennsylvania, I. 152, 176; II. 144. $12,000 were appropriated for steeple, clock and bell. The bell weighed 4275 pounds and cost $1923.75.

new city hall, built on the square which Penn had selected as a civic centre two hundred years before,[271] was ready for occupancy towards the end of the century. Then, on the removal of the courts to the new city hall in 1895,[272] some of the old buildings were used for a few years by classes of the University of Pennsylvania, men gaining their first knowledge of the law in Congress Hall and studying the Constitution of the United States only a few feet from the room in which the Constitution was framed.[273] Mr. Justice Roberts was one of those students.[274]

But such uses did not continue long. Within a few years all of the buildings constructed after the seventeen nineties were removed and efforts were gradually made to restore the historic buildings and the square to the conditions of earlier times.[275] However, there had been no stable conditions which could be reproduced. Both the buildings and the square had been altered considerably during the course of the eigh-

[271] Note 83.

[272] Pennypacker, *Congress Hall*.

[273] On the appearance of the exterior of Congress Hall at that time see U. of Pa. Proceedings at Dedication of New Building of Law School, facing p. 5. The southern part of the former chamber of the House of Representatives was used by some classes. In a building immediately west of the State House but torn down before 1900 other classes, including the one on constitutional law, were held. That building is shown in Pennypacker, *Congress Hall*, facing p. 28.

[274] William Draper Lewis was dean. The faculty included George Wharton Pepper, George Stuart Patterson, C. Stuart Patterson and George Tucker Bispham. Francis H. Bohlen had taught in the law school and he soon rejoined its faculty.

[275] Shortly after June, 1898, the first floor of the State House was restored and the nineteenth century structures east and west of that building were replaced by wings and arcades which were more like those of the eighteenth century: see views cited in note 273 and citations in present note. In 1914 and later, other alterations in the buildings on the Square were made and these were under the advice of the Philadelphia chapter of the American Institute of Architects. (*Proceedings of American Institute*, 1915, 123; 1916, 92; 1918, 119; 1919, 166; 1922, 101; 1924, 128.) The recent changes in the Representatives room in Congress Hall were made under other auspices. Some of them were warranted by contemporary descriptions, but they do not appear to allow accommodations for all of the 105 or more Representatives: note 155. In the restoration of the building which was made under the auspices of the Institute some twenty years before, a platform found in the Senate chamber was allowed to remain there because of the absence of knowledge of sufficient reasons for removing it; but the fact that contemporaries who described both rooms mentioned a platform in the House without mentioning one in the Senate may be entitled to some weight and so may the fact that the carpet in the Senate chamber, as described in the *Gazette of the United States* for June 22, 1791, had such a pattern as to indicate that the floor was on one level in 1791.

teenth century. Therefore we have not been shown the appearance of the group at any one particular period. The group today is not as a whole as it was in 1776 or in 1787 or in 1790 or in 1800. Yet as we walk through the halls in which history was made we can in large measure see them as they were seen by the great men who here wrought so well.

And thus our study of the homes of the Supreme Court in New York and Philadelphia comes to an end. It has been long and possibly too exhaustive. But we have been thinking of more than bricks and mortar and times long since dead. The places which have held our attention have stood out from others of the past as the early habitations of those whose decisions have affected our country profoundly and will continue to do so.

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A TÆNIODONT SKULL FROM THE LOWER EOCENE OF WYOMING[1]

C. LEWIS GAZIN

(*Read by title April 25, 1936*)

Abstract

In 1931 the Smithsonian Institution expedition to the Big Horn Basin, under the direction of C. W. Gilmore, was extremely fortunate in securing the skull and lower jaws of the little known tæniodont, *Ectoganus gliriformis* Cope. The specimen was collected by G. F. Sternberg in Gray Bull beds about eight miles northwest of Worland, Washakie County, Wyoming. Heretofore "Wasatch" tæniodonts have been known only from very incomplete remains, and except for a lower jaw collected by Wortman in 1881, the described material consisted only of fragments of bones and teeth.

The skull is almost complete, though somewhat broken and distorted, and includes most of the permanent teeth and a portion of the milk dentition. The greater part of both rami of the mandible are preserved and a few of the lower teeth. The specimen is of special interest in demonstrating that teeth belonging to the type of *Ectoganus gliriformis* are the deciduous and little worn permanent teeth of what has been called *Calamodon*. Since *Ectoganus* is the earlier name (in pagination, Cope 1874), *Calamodon* becomes a synonym. Moreover, some of the specific names which have been applied are synonyms since they were based essentially on differences between upper and lower teeth.

In 1931 the Smithsonian Institution expedition to the Big Horn Basin, under the direction of C. W. Gilmore, was extremely fortunate in securing the skull and lower jaws of the little known tæniodont, *Ectoganus gliriformis* Cope. The specimen was collected by G. F. Sternberg in Gray Bull beds about eight miles north and west of Worland, Washakie County, Wyoming. Heretofore "Wasatch" tæniodonts have been known only from very incomplete remains, and except for a lower jaw collected by Wortman in 1881, the described material consisted only of fragments of bones and teeth.

The skull, U. S. Nat. Mus. no. 12714, is almost complete, though somewhat broken and distorted, and includes most of the permanent teeth and a portion of the milk dentition. The greater parts of both rami of the mandibles are preserved and a few of the lower teeth. The specimen is of special interest

[1] Published by permission of the Secretary of the Smithsonian Institution.

in demonstrating that teeth belonging to the type of *Ectoganus gliriformis* are the deciduous and little worn permanent teeth of what has been called *Calamodon*. Since *Ectoganus* is the earlier name (in pagination, 1874), *Calamodon* becomes a synonym. Moreover, some of the specific names which have been applied are synonymous as will be indicated on the following pages.

Description of Skull. The skull (Pls. 2 and 3) of this individual is relatively small compared with material of *Psittacotherium multifragum* from the Torrejon, as figured by Wortman (1897) and Osborn (1907), but this is probably due to the immaturity of the specimen. Youthfulness is indicated not only by the teeth but by the sponge-like texture of much of the bone surface. The skull is noticeably slender, although in the rostral portion this is largely effected by transverse crushing. Moreover, the rostrum has been somewhat twisted, placing the left maxilla and dentition lower and more forward than the right. The nasals are broad and extend posteriorly about 15 mm. behind the postorbital processes, where they terminate rather bluntly. The premaxilla is preserved on the left side between the canine and nasals, extending upward and posteriorly from the incisor as a slender wedge to a point nearly as far back as the postorbital processes. Apparently the canine at this immature stage was not entirely covered, or sheathed only by thin bone, as the maxilla and premaxilla, although somewhat broken along their margins, thin abruptly and do not meet over the canine. The anterior margin of the orbit is located above a point about midway between P^3 and P^4. However, its relative position undoubtedly changed with age. The infraorbital foramen is of moderate size and terminates anteriorly above P^3. The postorbital processes are low, blunt prominences, with subdued or only weakly developed temporal ridges extending back to the sagittal crest. A small but conspicuous process is present on the anterior margin of the orbit at about the position of the lachrymal bone. The zygomæ appear relatively weak for the heavy jaws possessed by this animal, but their slenderness may also

be attributed to immaturity. The arch arises from the lower margin of the orbit, above P^4 and part of M^1, and extends posteriorly to a position well back on the cranium. The posterior extremity of its upper margin is continuous with the lambdoidal crest and the lower margin widens to form the glenoid fossa.

The cranium is quite unlike the restoration figured by Wortman for *Psittacotherium*. The braincase is small and the sagittal crest markedly developed, becoming increasingly prominent posteriorly. This development of the crest is especially noteworthy in view of the youth of the specimen. The temporal fossa is large and rather smooth, and aligned near its posterior margin, as observed on the left side, are a series of 5 or 6 foramina, three of which are in the squamosal. A single large foramen set off from the others pierces the parietal at the base of the sagittal crest and at the deepest point in the fossa.

The occiput is high and triangular in posterior view, with a prominent, backward extending inion. The lambdoidal crests are outstanding and extend laterally to the unusually heavy and prominent mastoid processes. The basicranial region is broad and relatively short antero-posteriorly. The postglenoid processes are rugged and placed noticeably inward with respect to the simple, gently concave glenoid fossæ. The postglenoid process is separated from the periotic portion with the bulbous mastoid process by a smooth transversely elongate groove or depression for the audital tube. Apparently neither the bulla nor the audital tube were ossified.

The principal foramen in the sphenoidal wings is the large, horizontally elongate foramen lacerum anterius or sphenoidal fissure located between the orbitosphenoid and alisphenoid. Apparently *Ectoganus* had reached a stage of development in which only the optic foramen had become distinct from the sphenoidal fissure, and this only in the outer or anterior portion as the two are confluent internally and enter the cranium through a single opening a short distance anterior to the

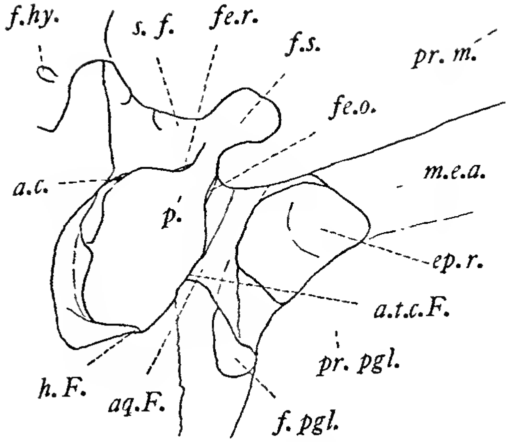

FIG. 1. *Ectoganus gliriformis* Cope. Camera lucida drawing of ventral surface of periotic region on right side of skull, U. S. Nat. Mus. no. 12714, corresponding to Pl. 1, Fig. 1. Scale about twice natural size.

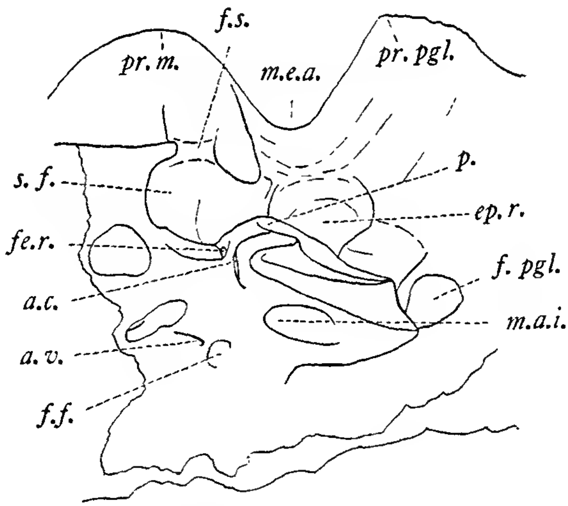

FIG. 2. *Ectoganus gliriformis* Cope. Camera lucida drawing, medial view, of periotic region on right side of skull, U. S. Nat Mus. no. 12714, corresponding to Pl 1, Fig. 2. Scale about twice natural size.

a.c., aqueductus cochleæ.
aq.F., open portion of aqueduct of Fallopius or facial canal.
a.t.c.F., outer or tympanic aperture for canalis Fallopii.
a v., aqueductus vestibuli.
ep.r., epitympanic recess.
fe.o., fenestra ovalis (or vestibuli).

petrosal. The foramen rotundum and foramen ovale are not present and there is no alisphenoid canal. This apparently represents the primitive condition in which the second branch of the trigeminal nerve passed through the sphenoidal fissure along with the first branch and the third, fourth and sixth nerves, the foramen rotundum not having become partitioned off. Inasmuch as the foramen ovale is not distinct, the third branch of the trigeminal presumably made its exit postero-ventral to the sphenoidal fissure through the large opening anterior to the petrosal in about the position corresponding to the foramen lacerum medium. In the posterior portion of the basis cranii, however, the hypoglossal or condylar foramen is distinct from the foramen lacerum posterius.

Petrosal. Though incomplete on the left, the petrous portion of the periotic is entirely preserved on the right side (Figs. 1 and 2 and Pl. 1, Figs. 1 and 2). It projects prominently forward and medially from the mastoid portion. Anteromedial from the fenestræ the petrosal in ventral view (Fig. 1, Pl. 1, Fig. 1) is almond-like in shape, and exhibits a marked promontorium close to the postero-laterally directed spur separating the two fenestræ. The fenestra ovalis faces laterally and slightly forward toward the medial extremity of the channel for the audital tube. The fenestra rotunda faces almost directly backward and slightly downward. Along the medial and anterior margin of the projecting portion there is developed a conspicuous sulcus or groove, presumably in part for the entocarotid artery, and perhaps also in part as a venous sinus. At the antero-lateral extremity of the groove

fe.r., fenestra rotunda (or cochleæ).
f.f., probably the floccular fossa.
f.hy., hypoglossal foramen.
f.pgl., postglenoid foramen.
f.s., stylomastoid foramen (primitive ?).
h.F., hiatus Fallopii.
m.a.i., internal auditory meatus.
m.e.a., channel for external auditory meatus.
p., promontorium.
pr.m., mastoid process.
pr.pgl., postglenoid process.
s.f., possible location of stapedial fossa.

there is a small foramen which is apparently the hiatus Fallopii for exit of the major superficial petrosal nerve.

Lateral to the projecting portion of the periotic the roof of the audital cavity shows a prominent channel for the facial nerve, which is of particular interest in being open for the entire distance between the geniculum and the simple stylomastoid opening. The facial nerve after passing through the internal auditory meatus to the bend in the aqueduct of Fallopius would enter the open part of the canal. At about this point the superficial petrosal nerve normally separates from the facial and passes forward, in this case apparently to reenter the petrosal close to the open anterior extremity of the channel. A short distance farther forward this nerve would reappear in what is believed to be the hiatus Fallopii. The major portion of the facial nerve passes postero-laterally along the facial canal to the stylomastoid opening which in *Ectoganus* is little more than a notch in the antero-medial margin of the ventral surface of the periotic.

Antero-lateral to the open canalis Fallopii, opposite the fenestra ovalis, and just above the medial extremity of the channel for the audital tube is a large epitympanic recess, which is separated medially from the facial canal by the tegmen tympani. Posteriorly this partition curves sharply outward and slightly forward, markedly widening the facial canal, and leaving a slight pocket below and behind the lateral extremity of the partition.

The exact location for the origin of the stapedial muscle is not known but it was probably in some part of the large cavity posterior and lateral to the fenestræ and perhaps medial to the posterior portion of the facial canal.

A short distance antero-medial to the epitympanic recess and apparently outside the tympanic fossa is a rather large post-glenoid foramen which is situated distinctly medial to the post-glenoid process, presumably continuous with the complex of foramina or venous sinuses visible on the outer surface of the parietal and squamosal.

In medial view (Fig. 2 and Pl. 1, Fig. 2) several apertures

are visible on the dorso-medial surface of the periotic, the most conspicuous being the antero-medially directed internal auditory meatus which occupies a large portion of the dorsal surface of the projecting part of the petrosal. Above and behind the internal auditory meatus and a short distance medial to the fenestra rotunda is the small opening of the aqueductus cochleæ. Postero-lateral to the internal auditory meatus and between two prominent fossæ is the antero-ventrally directed slit-like aperture of the aqueductus vestibuli. The fossa antero-lateral to the aqueductus vestibuli is probably that for the floccular lobe of the cerebellum. A large depression on the medial surface of the periotic near the ventral margin and posterior to the position of the foramen lacerum posterius appears to be a part of a more general cavity opening posteriorly into the condyloid sinus. The condyloid sinus in the exoccipital is double anteriorly and appears to be entirely separate from the hypoglossal foramen.

Superior Dentition. The skull is unique not only in being so nearly complete but in exhibiting the dentition at a stage in which the fourth milk premolars are retained and the permanent teeth are just erupting or are only slightly worn. This association goes far toward clarifying the relations between several of the forms which have been described from lower Eocene beds both in New Mexico and Wyoming.

The dental formula for the upper jaw is the same as that recognized by Wortman for the lower jaw, which includes one incisor, a canine, and a full complement of cheek teeth. The first upper tooth, presumably I^3, is a hypsodont, strongly curved, rodent-like incisor which increases markedly in antero-posterior diameter toward the alveolus. Enamel is present only on the anterior surface, extending part way around on the outer surface and only a slight distance back on the medial surface. The enamel is smooth near the occlusal surface but is slightly roughened more distally. The flattened oval cross section of the tooth is somewhat more convex on the outer side and shows a slight ridge at the posterior margin of the enamel. The occlusal surface of the tooth, together with

that of the incisor on the opposite side, is smoothly convex. Parts of two slightly worn incisors, apparently upper, are included in the type material of *Ectoganus gliriformis* and were figured by Cope in 1877 (Pl. 41, Figs. 4 and 5). A third incisor in this material is less tapering and may belong to the lower jaw (Pl. 41, Fig. 6). A somewhat less flattened incisor tooth is included in the material which Cope referred to *Calamodon simplex*. This may also be from the lower jaw (Pl. 43, Fig. 5).

The greatly enlarged second tooth, which Cope believed to be a lower incisor (I_2), has been shown by Wortman to be the canine in the case of *Psittacotherium*. In the *Ectoganus* skull this tooth lies for a greater part of its length in contact with both the premaxilla and maxilla, as would be expected for the canine. Its growth is from an origin well back in the rostrum, some distance posterior to the anterior extremities of the frontals. The canine is immediately postero-lateral to the incisor, without a diastema such as shown in *Psittacotherium multifragum*. Enamel covers the anterior surface of the canine and the anterior portion of the lateral surfaces, extending slightly farther back on the outer wall. The outer surface is moreover characterized by a prominent longitudinal ridge at the margin of the enamel, and immediately anterior to this, a more or less grooved depression. The inner surface is more evenly convex, less noticeably grooved, and with only a slight ridge at the enamel margin. Posterior to the enamel the tooth is more compressed transversely and acutely convex behind. At the stage of development reached in this skull the occlusal extremity of the tooth is of small diameter but increases markedly in size toward the frontals. Included in the type material of *Ectoganus gliriformis* are the crown portions of two upper canines which are not greatly worn and represent a stage nearly comparable to that in the skull at hand. Upper canine fragments in the type of *Calamodon simplex* are from mature sections of the tooth in a more adult animal. These and the *E. gliriformis* canines were described and figured by Cope as lower incisors (1877, Pl. 41, Figs. 2–3; Pl. 44, Fig. 4).

The first upper premolar is a small, prismatic tooth, with a triangular cross section, the broadest side of the triangle being parallel to the postero-internal wall of the canine. Wear has modified the occlusal surface so as to remove any trace of cusps. Enamel is present on the outer wall, extending a short distance around the anterior angle of the tooth near the occlusal surface. A small patch of enamel also remains on the postero-lingual angle at this stage of wear. Through occlusion a deep pit has been worn in the postero-external portion of the grinding surface, opening broadly on the postero-external surface.

The second premolar is the largest tooth in the cheek series. Its crown is only slightly worn and exhibits two prominent cusps, one internal and the other external. The tooth is transversely broad with the widest portion well forward. The anterior surface shows a marked concavity extending longitudinally, across which the enamel does not close above the saddle between the cusps. The posterior surface is apparently convex as far as can be observed in the skull and the enamel divides distally from the crown a short distance from an enamel pocket in the posterior portion of the saddle. Apparently the enamel continues for some distance along the inner and outer surfaces of the tooth, extending around on the posterior surface somewhat more than on the anterior. The type of *Ectoganus novomehicanus* (Cope) is an isolated, partially worn second upper premolar which Cope (1877, Pl. 40, Figs. 34–39) thought to be the crown portion of an upper canine ("superior incisor-tooth"). Except for greater wear this tooth shows no important differences from that in the skull.

P^3 is a large oval shape tooth with slightly flattened anterior and external surfaces. The tooth is in a position of having just erupted, and although the crown is not completely preserved in either maxilla, its unworn occlusal surface consisted apparently of a cup shaped basin surrounded by a tuberculate rim. The crown portion was completely covered with enamel, but the distribution of enamel away from the crown cannot be seen without damage to the specimen.

The crown of the fourth premolar is almost entirely hidden by the deciduous fourth premolar, however, the tooth was apparently oval in cross section and at least the anterior portion of the crown as exposed, and probably the entire crown, was covered by enamel. A relatively large cheek tooth belonging to the type of *Calamodon simplex* (1877, Pl. 44, Fig. 3) may be a fourth upper premolar. The tooth is well worn, but still shows a vestige of a fold or valley on the postero-external portion of the occlusal surface and a considerable extent of enamel up the inner wall of the tooth. In size it may be somewhat larger than the tooth in the skull.

Dp^4 is a short crowned tooth with three roots, one prominent postero-lingual root and two unequal external roots, the anterior being the better developed. The tooth is badly worn but still shows a conspicuous reëntrant from the external wall. Enamel is continuous around the margin of the wearing surface and projects a short distance up each of the root portions of the tooth. Both right and left Dp^4 are included in the type of *E. gliriformis*. These, however, are slightly less worn than in the skull and the enamel pattern on the occlusal surface is not so nearly obliterated. Cope (1877, Pl. 44, Figs. 7–8), because of the incompleteness of the material which he had at hand, did not recognize them as milk teeth.

The first molar is smaller than the premolars immediately preceding and its occlusal surface exhibits two transverse lophs, the anterior of which is the broader and antero-posteriorly covers a greater portion of the crown area. The valley between the crests opens buccally through a deep notch between the outer cusps of the crests and continues on the outer wall of the tooth as far as can be observed as a deep longitudinal groove. Lingually the crests approach one another more closely and the notch between them is shallower. The groove on the lingual wall of the tooth is less conspicuous than on the outer side and is obliterated a short distance from the occlusal surface. The antero-external and postero-internal portions of the tooth are outstanding laterally and medially, causing the greatest diameter to be obliquely outward and forward across the tooth.

The second molar is about the same size or slightly smaller than the first molar. Only the inner wall of the crown, showing the lingual extremities of the lophs, is preserved. In this tooth the posterior crest was apparently much narrower than the anterior crest, as indicated by the outline of the alveolar portion of the tooth. Also the outer wall of the alveolar portion of the tooth shows a deep longitudinal groove. Except for the notch at the occlusal surface in the unworn tooth, the lingual wall is smoothly convex. M^3 is not preserved, only the anterior wall of its alveolus remains to demonstrate the former presence of the tooth.

Mandible. The mandibles (see Plates 4 and 5) belonging to the young skull of *Ectoganus gliriformis*, though not complete, are distinctly smaller than the lower jaw of "*Calamodon*" *simplex* as figured by Cope (1884) and Wortman (1897). The rami do not deepen anteriorly so rapidly below the cheek teeth as Cope's specimen and the canine does not extend so far posteriorly beneath the molars; conditions which may be attributed to the difference in maturity between the two individuals.

Inferior Dentition. The lower incisor is not preserved, and only the basal portion of the canine can be seen. The lower canine, as that in the upper jaw, has enamel only on the anterior portion, but the ridge along the posterior margin of the enamel on the outer side is not nearly so outstanding as in the upper canine, and the external enamel surface is apparently not so deeply grooved. The tooth is relatively narrower between the posterior enamel margins than in the upper canine, and although constricted transversely just posterior to the enamel margins, from the constriction back to the posterior convexity the thickness is nearly uniform. The basal portion of the lower canine is preserved in the fragmentary lower jaw which is the type of *Calamodon arcamœnus*, and other canine fragments figured by Cope as part of this type may belong to the same tooth (1877, Pl. 42, Figs. 1–4). An isolated lower canine (1877, Pl. 41, Figs. 13–17) was referred by Cope to the same species. Cope

recognized the true position of this tooth in the lower jaw but regarded it as an incisor.

P_1 is not preserved in either jaw but the remaining portion of the alveolus shows that the tooth had a nearly triangular cross section and was wedged between the postero-external surface of the canine and the anterior wall of the second premolar.

The second premolar is the largest tooth in the lower post-canine series, resembling somewhat the corresponding tooth in the upper jaw. P_2 is relatively broad transversely and flattened on its anterior face. The crown is composed of two cusps or columns, the outer column being longer, antero-posteriorly thicker, and more curved than the inner portion. The posterior wall of the tooth shows a marked concavity between the columns, which is broader and more open away from the crown. Enamel is present on the inner and outer columns of the tooth, on the postero-internal and postero-external surfaces respectively. Enamel is absent from the greater part of the flattened anterior surface below the saddle between the cusps, but extends around on the posterior portions of the columns to the depression between them, where it is again absent from the saddle down. This tooth differs from P^2 essentially in having its anterior wall more flattened and its posterior surface markedly concave, but with the broad outer convexity forming a rounded though somewhat more acute angle with the anterior surface than with the posterior surface in both upper and lower second premolars. The crown portion of this tooth in the type of *Ectoganus gliriformis* was thought by Cope (1877, Pl. 41, Fig. 1) to be the crown of the upper canine, which he classified as an upper incisor. A much worn and more mature section of a second lower premolar was referred by Cope to *Calamodon simplex* (1877, Pl. 43, Fig. 1), also wrongly identified as an upper "incisor." However, in 1882, in describing the lower jaw of *Calamodon simplex* Cope recognized the true position of this tooth in the lower series, but was inclined to regard it as a canine, considering the first three teeth as incisors.

P_3 is not preserved in either ramus of the mandible and the crown portion of the fourth premolar in the left mandible is obscured by the fourth milk premolar. In the right ramus the crown is broken away and only the general outline can be observed. At the section presented the tooth was apparently surrounded by enamel, but probably the enamel was divided on the anterior surface in more advanced sections as indicated in the lower jaw figured by Wortman. P_4 is a large tooth, somewhat broader across the anterior than the posterior portion, and with its greatest antero-posterior diameter across a distinctly lingual portion of the tooth.

The deciduous fourth premolar is a short crowned tooth with an anterior and a posterior root. The roots are about as wide as the tooth, antero-posteriorly compressed and diverging over the crown of the permanent premolar. The crown of Dp_4 is elongate antero-posteriorly, and although much worn it apparently had an anterior and a posterior transverse crest, connected by a somewhat oblique ridge near the middle of the tooth. Although larger and relatively more elongate, this tooth is suggestive of the brachydont first lower molar in *Wortmania otariidens* (Cope) (1888, Pl. 4, Figs. 2, 6) from the Puerco. A slightly less worn lower deciduous fourth premolar is included in the type of *E. gliriformis*, associated with upper milk premolars. It was this tooth which Cope (1874) described as having an S-shaped pattern, and which he figured in 1877 (Pl. 41, Fig. 10) as a lower molar.

The lower molars are quadrate, four cusped teeth, with the cusps arranged to form an anterior and posterior crest. Extending forward and inward from the posterior cusps in M_1, and to a less extent in M_2, are two low spurs, tending to divide the deeper part of the transverse valley into two small pockets, one to the outer side of each spur. In M_3 the posterior cusps are more distinctly separated from the anterior pair, and from each other. In all three molars the width is greatest across the anterior portion. M_1 is a little longer than M_2, and M_3 is distinctly smaller than either. Enamel covers the entire crown of each, except where removed by wear. Distribution

of the enamel below the exposed crown cannot be seen, but its vertical extent was probably not so great as in the larger premolars. Associated with the type lower jaw of *Calamodon arcamoenus* is a molariform lower tooth (Cope, 1877, Pl. 42, Fig. 5). This tooth is a little larger than the first lower molar in the mandible belonging to the skull under discussion. It may represent a larger individual, or perhaps be a fourth lower premolar, as the unworn crown of the latter cannot be seen in the jaw.

Remarks. In summarizing it may be pointed out that the various names which have applied to Wasatch stylinodonts were based for the most part on tooth materials in different stages of wear or maturity, and on distinctions between teeth thought to occupy corresponding positions but here recognized to occur in different positions in the dentitions. Thus the genotypes, *Ectoganus gliriformis* and *Calamodon simplex*, were distinguished by the difference between a slightly worn and a mature section of an upper canine (described as a lower incisor), between an unworn and a mature section of P_2 (first described as an upper incisor) and between milk premolars and a permanent cheek tooth. The species *Ectoganus novomehicanus* was distinguished from *E. gliriformis* on the basis of the differences between an upper second premolar and a lower second premolar, both thought to be the crowns of the large upper "incisor." *Calamodon arcamœnus* was distinguished from *C. simplex* essentially on the differences between a lower and an upper canine, both being regarded as belonging to the lower jaw.

The type of *Dryptodon crassus* Marsh (1876) has never been figured but the difference which Wortman observed (1897) between it and the lower jaw of *Calamodon simplex* which he described is essentially in the manner in which the enamel is distributed around the crown of P_4. In *Dryptodon* it is stated that the enamel completely surrounds the tooth, and in the *Calamodon* jaw, which has well worn teeth, the enamel is discontinuous. In the *E. gliriformis* mandible herein described the broken P_4 is surrounded by enamel, hence

it would appear that this character is of little or no value, particularly since the observed distribution of enamel around the tooth varies with wear and the extent to which the tooth has erupted.

From the foregoing it appears that only *Ectoganus gliriformis* has any standing as a name for Gray Bull stylinodonts, however, there still remains the matter of size and a doubt as to whether the immature jaw here figured would in maturity reach the proportions of the "*Calamodon*" jaw figured and described by both Wortman and Cope, or the mandible fragment belonging to the type of "*Calamodon arcamœnus*." Moreover, the upper cheek tooth in the type of "*C. simplex*" and the lower molar in the type of "*C. arcamœnus*" are somewhat larger than teeth in what are believed to be the corresponding positions in the present skull and jaws of *Ectoganus gliriformis*. This suggests that perhaps a second species, *Ectoganus simplex*, should be recognized, which from our present knowledge is distinguished from *E. gliriformis* only on somewhat larger teeth.

Little can be added to what has already been written, particularly that by Simpson (1931), regarding the relationships of the Tænidonta. The cranial portion of the *Ectoganus* skull is not so much like that of a gravigrade sloth as Wortman figured the restoration of the skull of *Psittacotherium*. The dental development from *Wortmania* to *Stylinodon*, though approaching in a striking way the dentition of the ground sloth, is apparently a case of convergent development. It is highly probable that these forms represent an order distinct from the Edentata, and there is no certainty as to how near or remote are the two ancestries, as most of the edentate resemblances become more obscure as we retrace the stylinodont line back to *Wortmania*. Moreover, it seems preferable not to include these forms, as Winge does, in the Insectivora.

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FIG. 1. *[illegible]* Cope. Ventral view of periotic region on right side of skull, U. S. Nat. Mus. no. 12714. Specimen is oriented with anterior portion directed downward. Scale about twice natural size. Grey Bull Eocene, Big Horn Basin, Wyoming. Photograph by C. E. Resser.

FIG. 2. Medial view of same. Specimen is oriented with ventral surface upward and anterior extremity to right. Scale about twice natural size. Photograph by C. E. Resser.

[illegible] Cope. Lateral view of skull. U. S. Nat. Mus. no. 12714. Natural size. Gray Bull Eocene, Big Horn Basin, Wyoming.

[illegible] Cope. Ventral view of skull. U. S. Nat. Mus. no. 12714. Natural size. Gray Bull Eocene, Big Horn Basin, Wyoming.

PLATE 4

[illegible] Cope. Left ramus of mandible, U. S. Nat. Mus. no. 12714. 1, dorsal view; 2, lateral view; 3, medial view. Three-fourths natural size. Gray Bull Eocene, Big Horn Basin, Wyoming.

[illegible] Cope. Right ramus of mandible. U. S. Nat. Mus. no. 12714. 1, dorsal view; 2, mesial view; 3, lateral view. Three-fourths natural size. Gray Bull Eocene, Big Horn Basin, Wyoming.

BALL LIGHTNING

W. J. HUMPHREYS

(*Read April 25, 1936*)

ABSTRACT

In reply to widely published requests I received 280 personal accounts of "ball lightning." Those reporting range from children (at the time of observation) to eminent scientists, but all "saw" alike. These many cases, except, perhaps, two or three, readily reduce to a few classes: Brilliant flash at the point struck; persistence of vision; broken discharge path, giving separate flashes; meteorites; will-o'-the-wisp; falling molten metal; lightning seen end-on; brush discharge. There was no certain case of orthodox ball lightning, but there were many that for other reasons were highly interesting.

In 1924 I published a request for detailed accounts of "ball lightning" by those who themselves had seen it. This request, kindly copied rather widely, brought 180 replies. Its repetition in 1931 brought 100 replies. The observers, ranging, at the times of observation, from children with no formal training, to mature scientists of the highest order, all clearly gave faithful accounts of their experiences which, in most cases, had been such that time could not blur with a veil of forgetfulness. It took much trouble to write these replies, many of which had to be rather lengthy. I therefore wish to record here my sincere appreciation of the 280 authors of these letters who so generously have added to our knowledge of ball lightning.

Not one of these many accounts is unmistakably that of what ball lightning is supposed to be, that is, a leisurely moving and approximately spherical body of gas, electrons, or what not, luminous by virtue of its electrical state or condition. They do, however, divide into several different groups, each descriptive of a distinct phenomenon of sufficient interest within itself to justify a brief account in this connection. It must be remembered, though, that a faithful report does not necessarily, but often necessarily does not, correctly represent

the thing described. In the stress of danger and excitement things may not actually be what they truly seem, and at best an error in the judgment of distance entails a corresponding error in the estimate of size. Furthermore, to the somewhat nearsighted, as many are, a distant light is magnified beyond its correct dimensions. Nevertheless, all these numerous reports that have been sent to me are, in general, unmistakably clear, even when the correct explanation of the phenomenon described is not obvious.

Flash at Discharge Point. Many accounts of ball lightning describe a brilliant ball seen on the spot struck at the instant of discharge. This seeming greater flare presumably is real and caused partly by the supply of material by the solid struck and, in many cases, partly by the rich visible spectrum of this material in comparison with that of the air. Logic now causes many of us to "recollect" seeing this ball fall a greater or less distance onto the place of flare—logic suggests that it must have fallen, and recollection gives consent.

Sometimes the streak of lightning seems to contract along its length to a "ball" at the place struck. Apparently the luminosity persists longer here than at even a few feet away in the free air. I myself can testify to a distinct case of this greater persistence of luminosity at and near the place struck, as it was not seen until a fraction of a second after the discharge. I was at work at my desk when a vivid flash of lightning caused me to look suddenly through a window, whereupon I saw a javelin of yellowish light that faded rapidly sticking into the group chimney of a nearby hospital. The distance from my desk to the place struck was about 100 feet. Only a few bricks were knocked out, but in a second or two a great puff of smoke came from the chimney as from a cannon.

Persistence of Vision. Every one is familiar with the fact that even a momentary glimpse of the sun in a clear sky, or of any other exceedingly brilliant object, leaves a spot before the eyes that only slowly fades away. When the light is focused on the center of vision the spot is likely to remain more or less stationary in front of one and seriously to interfere

with seeing. When, however, the light is focused off-center the apparent luminous body is pretty certain to seem to move, often in a jerky or unsteady manner, owing to turning the eyes in an effort to see the supposed object directly. Clearly, since the luminous object now is only a condition at a certain place on the retina, it seems to move, as, when, and to the extent that, the eye itself moves. Seeing it directly, or centering our eyes upon it, therefore is impossible. We may turn our eyes quickly the apparently necessary amount to see it clearly, but instantly it is gone farther on, and we try again and again, and thus give the supposed object a jerky motion. Or, as more commonly happens, we may instinctively expect a luminous object, resembling a glowing ball a few inches to a foot or so in diameter, to move smoothly through the air or over a level surface, as balls are wont to do, and that is how the apparent object commonly does move for us—we know how it ought to move, and our eyes in anticipation carry it along just that way.

All this and a lot more applies to the after-image left in the eye when we happen to see lightning hit a particular spot, or catch a glimpse of some other brilliant portion of the streak that is, or seems to be, condensed into a small space. Imagination, or recollection of what our experience has been with real objects more or less like that which our eyes insist we are now seeing, supplies a lot of additional sensations which are quite as distinct to us as if they actually had been caused in the manner supposed, nor is any one of our senses above offering false testimony to the reality of the unreal. The initial flash may have been a quarter of a mile away, or farther, and yet the "fire ball" our eyes bring in through a window or open door, glows as it floats about the room, gives off, sometimes, the pungent odor of burning sulphur, causes (rarely) prickling sensations and even a sense of heat, leaves quietly, if through an open space, or bumpity-bump if it chances to roll down a flight of stairs with a bounce on every step, for all the world as a real ball normally would do. Even if you run from it into another room there it will be too and stay until it slowly fades or you quickly faint.

Every one of these things is described in detail in the letters kindly sent to me on this subject. Here is an interesting account written on Jan. 19, 1925, at Tauranga, New Zealand, by Mr. G. H. Bell: "Years ago," he says, "while milking cows in an open shed a thunderstorm came over and I 'saw' a fireball some feet in diameter shoot towards me. Lost a moment behind logs it reappeared in the stockyard and I felt a hot glow as it glided past a few feet from me right through the shed. I failed to determine its course after that as my sight seemed confused, and I congratulated myself on a narrow escape from death.

"Now a most remarkable feature of the incident was that the cows, the most nervous of animals, gave not the slightest heed to it, and long did I ponder on this aspect. Years afterwards while closely staring at an electric light point the light was switched off, but I still 'saw' the bright globe slowly moving on the wall. Only then did it occur to me that my 'lightning ball' of years before had been 'all my eye' in the truest sense of the term."

I do not know what Mr. Bell's formal training in science may have been, but certainly he had caught its spirit and that is what mostly counts.

In many cases the balls seen outdoors appear to fall to the ground, as real balls do, other than balloons, and some of them bounce in their course from once to a number of times, the eye in anticipation making the fictitious object move substantially as a real one might.

Most of the clear cases of persistence of vision are reported as seen by but one person. Other reports however say that two or more persons saw the same thing. Details are lacking, however, to show that they saw precisely the same movements and other particulars that would prove objective reality. A few observers report noticing the ball growing dimmer and smaller as it moved along. Many report that the ball exploded with a crash. This crash evidently was the thunder that had just reached the observer, after which the ball, having exploded, was no longer "seen."

Here is another interesting case that appears to involve persistence of vision, quoted in full because of the scientific training and ability of the observer, Mr. G. W. Lewis, Director Aeronautical Research, National Advisory Committee for Aeronautics. He says:

"One afternoon in the spring of 1923, following a rather severe thunderstorm, I was surprised to see, from my home in Chevy Chase, Md., a ball of light about the size of a toy balloon approximately 125 feet away in the adjacent woods. It was 8 feet, roughly, from the ground, and in a few seconds had moved in my direction 100 feet, or so, when, at the height of 7 feet, it came in contact with a tulip tree. At this place a cloud of dust was formed by a dynamite-like explosion so loud that neighbors came out of their houses to see what had happened.

"I immediately examined the tree and found that the explosion had occurred where two nails had been driven into the trunk. There were no wires or connections of any kind attached to the tree. The bark was shattered at the place struck and so loosened from the trunk all around that the tree died."

A possible explanation of this experience, in general keeping with many others, would be that somehow an after image had been formed in the eye by a brilliant light that seemed to the observer, when he first became aware of it, to be only a short distance, 125 feet, away, but which actually may have been much farther off. Then as the image was being followed in the usual way the tree was struck by lightning near to where the seeming ball then appeared to be. According to this idea, the moving luminous ball, an after image, and the striking of the tree were related only as coincidental occurrences, and not causally connected. However, such were the experiences, which I am permitted to quote, of a trained scientist, interpret them as we may.

Reflection from Convex Surfaces. A few persons have been startled by the reflection of a brilliant streak of lightning by a polished convex metal surface, such as that of a kitchen pan, a door knob and the like, and reported what they saw to be ball lightning.

Place-to-place Discharge Indoors. When a house is struck

by lightning it often happens that a portion at least of the current jumps across one or more air gaps and at each such place produces a brilliant flash. Such flashes occasionally are referred to, by those who have seen them, as ball lightning, as also are the after images which such flashes leave in the eye. Telegraph keys, wall telephones and lightning arresters at power houses are, or at least formerly were, the starting points of many a ball of lightning—a brilliant spark, owing to the wire being struck somewhere, and its after image.

Lightning Discharge Outdoors along a Broken Conductor. Obviously there is a brilliant flash wherever lightning jumps a gap in a conductor, or takes the near way, as it does, across a sharp bend instead of following the wire, say, around the corner. When several such breaks occur in a row the consequent flashes, though occurring virtually simultaneously, may be mistaken for rapidly passing ball lightning. An excellent example of this type of ball lightning was brought to my attention some years ago, on which I took notes at the time, as follows: On Sunday afternoon, June 8, 1924, Mr. C. P. Thomas, a white mail carrier of Washington, D. C., parked his automobile on the side of the road to Fairfax, Va., pending the passage of a severe thunderstorm. When it was nearly over, a moderate flash of lightning was instantly followed by a ball of fire the size of one's double fist that swiftly passed 100 feet or so along the opposite side of the road, but within 20 feet of him. At one point on its course there was a sharp explosion with flying sparks followed by smoke.

On the following Thursday afternoon Mr. Thomas kindly took me to the scene of the ball lightning. There we at once found along the course the ball had taken the badly rusted remnants of an abandoned wire fence. The upper strand, about two feet above the ground and more or less covered by weeds, was partially fused in various places, especially where it was in contact with another wire, and at one place burned entirely in two. About 20 feet beyond the place the ball was last seen, and in the direction it seemed to be going, the wire

terminated *in* a large tree, presumably overgrown where it had been attached years before. Near the place the automobile had been parked the wire turned off at right angles to the road, went through woods some 75 feet and terminated on a tree that had been struck by lightning very recently as evidenced by the freshness of the skinned bark, plowed up dirt and wilted leaves. Quite evidently, then, a portion of the discharge that hit this tree turned off along the rusted wire and made the flashes that produced the impression of a swiftly passing ball of fire.

Several other occurrences of ball lightning have come to my attention that seem to have been caused in the same general way as the one just described.

Meteorites. In a few cases what appear to have been near-by meteorites have been reported as ball lightning.

Will-o'-the-wisp. Mr. Charles L. Searcy, writing from the University of Nevada on February 1, 1926, reports that in 1885 he and several others saw ball lightning one calm sultry night in Indiana. It looked like a ball of fire two to four feet in diameter, and moved in an irregular course near the surface of a long meadow ridge. At times it appeared to brush the ground and then quickly rose to the height of 10 to 15 feet. It passed by some 200 feet distant, and was visible three quarters of a mile away. Several neighbors also saw it. Its speed was moderate, something like that of a slow moving airplane.

For a recollection of 40 years this is a most excellent description of one of the recognized varieties of the will-o'-the-wisp, namely, an owl out on a hunting flight and covered with fox fire from a decaying hollow tree in which he had spent the day.

Falling Molten Metal. A shower of liquid iron is a thing to keep away from, and when it has been produced by lightning, as it sometimes is, it is likely to be somewhat startling. It is no wonder then that occasionally such glowing masses appear many times larger than they really are, especially to one who is appreciably nearsighted, and are reported as cases of ball lightning.

Lightning Seen End on. If one happens to see the lower portion of a lightning discharge end on, or nearly so, he is likely to report it, if he lives to tell the tale, as a ball of fire coming at him. He actually knows nothing, of course, about its direction of travel, but he is sure he didn't throw it and common sense (a composite of past experiences and not always reliable) tells him that it therefore must have come towards him. This testimony he accepts and under the circumstances that is the best he can do. Mr. J. W. Bernard, writing from Dermott. Ark., on July 18, 1931, says that in 1902 or 1903 a severe thunderstorm came on while he was in a field plowing. He was hurrying to the end of the row where he could unhitch his mule and find shelter, but before getting there sensed a pungent odor and heard a swishing sound that appeared to be behind him. On looking back to see what could be making this noise, he saw, he says, "a ball of lightning, about the size of a man's head, starting in my direction. I dodged down against the plow, or rung in the plow handles. The lightning seemed to burst between me and the mule. I felt the jar of the plow as it was jarred out of the earth, perhaps six inches. One plow handle was split off and remained in my hand; the other handle was split but remained on the plow. The mule fell to its knees, then sprang up and ran across the field. As the mule sprang to its feet I fell to the ground. I did not lose consciousness, but could not rise at once. I was shocked but not injured in any way."

The swishing noise and the pungent odor presumably were owing to a brush discharge, such as often occurs just before a flash of lightning and at the place about to be struck.

I have other similar accounts of this variety of ball lightning—lightning seen end on. One of them, a somewhat detailed account by a man *killed* by this variety of ball lightning, deserves being quoted. Oh yes, he came to two or three hours later, but he had gone through all the experience of being killed, and doubtless would have been buried without further consciousness if he had not come to. The man in question is Mr. Newton J. Dominy, postmaster at Dublin,

Ohio, whose account is dated August 18, 1931. He says the occurrence was about 4 miles southwest of Dublin, Ohio, in August 1896 and at 11:45 p.m. The ball which made a hissing roar and left a strong odor of burning sulphur (effects, both of them, obviously of the precursory brush discharge) was fiery red, changing to white, round and seemed to be about a foot in diameter. He further states that he was driving a horse and buggy in darkness that was pitch black, save only as relieved by frequent lightning, when suddenly this ball appeared with a streak of fire behind it. There was a hissing noise (due, presumably, to a precursory brush discharge, as explained above) and then suddenly the ball hit the left fore wheel of the buggy, knocking him, buggy, and horse into a ditch along the road fence. The horse was thrown on her back, the harness broken, the wheel struck torn off, and all its spokes except three jerked out of the hub, and they out of the felly. He remained in the buggy, hips on the seat, body bent forward between his legs, and top of head on the foot rest on the floor. Here he remained unconscious two and a half hours. The horse, still on her back, finally was gotten up but seemed dazed for days afterwards, and from that time on afraid of lightning.

As stated at the beginning of this article, there are several kinds of "ball lightning"; some are pleasing, and some just scary, but one experience with this end-on variety is quite enough for any sane observer.

Brush Discharge, Stationary. The brush discharge, coronal discharge, St. Elmo's Fire, or whatever else we choose to call it, is a well-known phenomenon that frequently has been called ball lightning. During dry and dusty periods it often occurs here and there along wire fences like so many candles set to light the way, and occasionally of dark nights produces a weird effect on the lonely cattle ranch by turning every steer into a devil with flaming horns! Sometimes in the midst of a thunderstorm two or three of these strange flames whirl and dance like dervishes on a chimney top, and then dive in with a crash as the lightning strikes. No wonder they often have been called ball lightning.

One man reports seeing, in the middle of the night as a thunderstorm approached, a sputtering sulphur flame (judging from the odor) six inches long on top of his iron bedpost. It lasted only a few seconds and went out with a bang. Spooky! but just a brush discharge.

Dr. A. J. Dempster, Professor of Physics, University of Chicago, kindly sent me an account of his own observation of what appears to have been an exceptionally large brush discharge that many would have called ball lightning. He writes: "The fireball that I observed occurred in Evanston, Ill., in front of the Patton gymnasium. A sudden electrical storm with heavy rain came up and three of us in a closed car had just passed in front of a streetcar which was stopped and taking on passengers when an especially intense lightning flash occurred. I looked back and noticed that the lights were out in the streetcar, about 30 yards away, and that on top sat a yellow ball of light about two feet in diameter. I was elated at realizing that I was seeing the rare phenomenon but was afraid that the passengers in the street car might have been injured. We stopped our car and got out in order to walk over, about 30 yards. Before we got far the fireball became faint and gradually disappeared. I would estimate the total duration as 10 to 15 seconds. Just as we got to the car the motorman threw his switch as apparently only his automatic cut-out switch had been set off by the flash. The car lighted up and went on with no one inside appearing aware of the occurrence of anything unusual."

If any one insists that this was not a brush discharge I shall not argue the point with him, but merely express the desire that he kindly will give me his interpretation of it, which indeed may be correct, or, at all events, nearer the truth.

The most spectacular display of the brush discharge that has come to my attention occurred in January 1924, on the ridge of a barn some 200 feet away from the observers, directly across a road and parallel thereto. The following account, written on December 16 of the same year, kindly

was sent to me by one of the eye witnesses, Mrs. R. Gilchrist.

"At six o'clock a.m. Mr. Gilchrist observed a light that appeared to be reflected from the barn through our window and remarked that a car might be coming. However, as the light persisted I arose and stepped to the window where my eyes were hurt by the glare. I immediately rushed to the phone to inform the owner of the barn that it was on fire, but in passing the large bay window in the living room I was so attracted by the light that I looked at it again and then saw that instead of the barn being ablaze there were balls of fire atop the roof. Mr. Gilchrist and our adopted son Edward were there by this time and we all gazed in astonishment at the wonderful spectacle.

"There were six incandescent globes or disks or hemispheres, it is impossible to state exactly which, upon the ridge of the barn, seemingly about three feet in diameter and spaced exactly even with a distance of six inches between their edges—for a distance of four rods around the barn everything was clearly illuminated.

"Edward then called our rapt attention to the disk on the north end of the barn with the exclamation: 'It's falling!' Sure enough it did fall, leaving the ridge with a sort of jump and landing, without loss of brilliance, half way down the roof, then bouncing from there over the eave and disappearing before reaching the ground. Immediately upon the extinction of the first light the second disk started to fall, and then the rest, one after another, in exactly the same way at regular intervals. Abruptly as the last one disappeared the light around the barn vanished and all was again dark. I at once looked at the sky and saw it was exceptionally clear, with no clouds and the stars very brilliant. An investigation in the morning showed that nothing had been disturbed and that there were no signs of anything out of the ordinary having taken place."

The following quotation from a letter by another eminent physicist, Leonard B. Loeb of the University of California, Berkeley, also is interesting. "I am particularly anxious," he assures us, "to record this experience in view of the fact that it occurred to me when I was a young child of some eight to ten years and, although I have never been imaginative and given to story telling, I was laughed at for my statement. I can, however, remember it as clearly today as when it occurred; incidentally at that age I had not heard of the phenomenon before, so it is not a figment of imagination. I do

not believe anyone else saw it, at least no one but my brother was near and he was much too young.

"It was during a summer thundershower in Springfield, Massachusetts, and must have been around 1898 or 1899. It was an afternoon thundershower, occurring, as near as I can remember, between three and five o'clock, probably at about four. The phenomenon occurred at the beginning of the storm, that is, as the main thundercloud was approaching; it was already fairly dark. I was indoors on account of the impending shower and was observing it from the front window of my grandfather's house. It occurred coincident with a striking of the lightning on the cornice or roof of a house across the street and one or two doors up. It preceded the thunderclap and the flash. As I looked out of the window I noticed a ball of what I would now describe as the color of active nitrogen or possibly slightly darker, as it seemed to me, descending from somewhat the direction of the neighbor's house in a light graceful curve. Its diameter appeared to be about double that of the toy balloons which one sees and its motion through the air was quite analogous to the motion of the type of air-inflated balloons which are used so frequently in modern dinner parties. It had a translatory motion in my direction and seemed to descend down an inclined plane from the approximate location mentioned. It appeared to strike on the lawn, bounced slightly once and then disappeared. Its disappearance was followed, better accompanied, by a tremendous clap of thunder and flash of lightning which appeared simultaneously. This was the flash which struck the cornice.

"There was no visible after effect and its outline, so far as I remember, was more or less indistinct, although it was quite spherical in shape. In the question of the sharpness of outline I am no longer definitely certain. As regards the direction of the wind, I am inclined to believe that it might have followed the direction of the wind, although at that particular time the lull between the up-draft and the thunderstorm wind was on.

It has been my impression, as I have thought of it in later years, that the phenomenon was caused by some type of intense glow discharge caused by the effect of the field of the approaching cloud on the cornice or some projecting angle of the building. It has been my impression in thinking of it that the so-called ball was internally in rapid rotation of some sort or that there was a vortex which gave it its shape. The color was definitely that of active nitrogen, as I have since seen active nitrogen in the laboratory."

I fully concur in the supposition that this phenomenon was started by an intense glow, or brush discharge, but strongly suspect that its graceful fall was the familiar travel of an after image, and its bouncing just what any "born" physicist would expect a ball to do and, if it were an after image, "see" it do. The crash of thunder distracted attention and the ball, doubtless already fading, was lost to sight.

Brush Discharge, Moving. This phenomenon also frequently has been called ball lightning. It is exactly like the stationary brush discharge, just described, except that by the wind, or otherwise, it is carried along from one place to another, following the locus, presumably, of the most intense or concentrated ionization. Ordinary telegraph and telephone wires furnish favorite routes for the brush discharge to travel along, but it is not exclusive in its choice of paths. On mountain peaks, for instance, it may run along the edge of a cliff or even jump from boulder to boulder—really, no doubt, disappear from one boulder and reappear on another close by. Thus, Professor Henry B. Ward of the University of Illinois, referring to a storm he and Dr. F. E. Clements of the Carnegie Institution of Washington were in on the top of Mt. Garfield, Colorado, says: "The storm was an electrical one and the display was very vivid. I recall seeing balls of fire roll along the rocks and drop from one to another."

I have one more variety of ball lightning to report, but only a single occurrence of it has come to my attention, and I do not know how even to classify that, let alone explain it. It was described by Dr. Joseph S. Ames, long-time professor

of physics at the Johns Hopkins University. In his letter of June 19, 1924, quoted with his explicit permission, he says: "Mrs. Ames was standing on a rug during a thunderstorm with her hand at her waist, one finger more or less extended. I was about five feet away and noticed the air between her finger and the floor was quivering so that it looked just like the hot air over a field. I noticed something rise slowly from the floor up towards her finger and then there was for an instant a small oblong fireball about the size of a pecan attached to her finger. It was not very bright and appeared to shine through a haze. There came a flood of lightning outside and the fireball disappeared."

Is there, then, no such thing as ball lightning? I don't know. I only know that many things have been called ball lightning that were something else. Possibly a wire 100 feet long, or longer if necessary, carried more or less vertically in the free air when the potential gradient is very high, would give a vigorous brush discharge at either end, the brighter of which (that at the anode) might be conspicuous in the dark and pass for ball lightning. A very fine wire would be sufficient, one that the winds of a severe thunderstorm could take aloft if one end of it were attached to some light object. This would be a rare occurrence of course, but so is genuine ball lightning, if it occurs at all.

Another possibility: Since the lightning discharge progresses intermittently with only the relatively short forward portion of each successive surge especially brilliant, it would seem that if the distance gained by each impulse were very small there might then be at the forward end of the discharge a manifestation of genuine ball lightning. Whether or not this concept is permissible must await our further knowledge of lightning.

The idea, often advanced, that ball lightning is a balloon of luminous gas without a wall appears to have made no progress on the road towards scientific acceptance.

WEATHER BUREAU,
WASHINGTON, D. C.

THE FACTORS CONTROLLING PRICES

JAMES W. ANGELL

(*Read April 24, 1936*)

Abstract

Prices are among the most important of all factors in our daily life and welfare. The forces which in turn influence prices materially are numerous, complex, and of quite different orders. Price changes are not caused *directly* by changes in the quantity of money, nor by changes in business activity, nor by changes in the price of gold. The Warren-Pearson theory of the relation between the general price level and the price of gold, which was adopted by the Roosevelt Administration in 1933, is naive in logic, and during the last three years has in largest part failed to work out in practical terms.

The type of price behavior which is most disastrous to our national welfare is large and frequent changes in prices. Such large and frequent changes are most commonly associated with similar changes in the total money volume of the nation's spending. Large changes in the total money volume of spending are in turn most closely associated with similar changes in the size of our total stock of money (currency and demand deposits taken together).

As a first approximation, I therefore propose that we endeavor to stabilize the size of the stock of money per capita, in order to make prices behave in more "desirable" ways. Stabilizing the stock of money in this fashion will not stabilize prices. But it will reduce the factors which cause prices to alter to a few major categories, none of which is likely to produce *large and frequent* price fluctuations. The unfettered maniac in our economic life today is frequent large changes in the money stock. But the forging and fitting of adequate shackles is not a task beyond our powers.

It requires no proof that prices are among the most important of all factors in our daily life and welfare. If prices are "too high," we all grumble, and talk bitterly about such things as misguided government policies, inflation, and social justice. If prices are "too low," we observe the accompanying fall of business activity with misgiving, and fear of a general economic paralysis assails us. Clearly prices are important to us, and clearly it would be highly advantageous if we could make prices behave in more desirable ways.

The group to which we naturally appeal, in order to find out how to make prices behave in ways we judge to be desirable, is of course the economists. Yet the results of making such an appeal, at the present day, are likely to be both dis-

appointing and even somewhat startling. We should find extensive and perhaps increasing disagreement among the economists as to what to do, in order to control prices and their changes. Moreover, we should find that most economists admit to possessing a remarkably inadequate body of knowledge, in any defensible meaning of the term "knowledge," as to what the factors are which really govern price movements themselves, and as to the working mechanisms involved. The economist has no such command over his empirical data and over his theoretical interpretations as does the engineer or the physicist, and has no such armory of tested therapeutic measures as does the physician. This situation is not wholly the fault of the economist. The facts he must deal with are complex, refractory, and difficult to measure quantitatively. He has no test-tubes, microscopes or controlled experiments to work with, and in the monetary field he has only rather recently begun to acquire and apply adequate analytic tools of other sorts. But the situation is one which the economist must himself recognize honestly, and it is one which should make him walk extremely softly when he tries to reach practical conclusions.

It is not even wholly clear what we mean when we speak of "prices" and "the problem of prices." As a first approximation, we usually mean the prices of *commodities*, and especially of those commodities which are themselves bought and sold by individuals—like bread, and unlike blast furnaces. But the factors which influence commodity prices are also apt to influence money incomes, and likewise the prices of other kinds of things, though with varying degrees of speed and uniformity; and changes in money incomes are apt to react on commodity prices, though again in varying fashions. From this complexity and variability of relationship, incidentally, comes much of the difficulty of the monetary economist's problem. In what follows, I shall have the prices of commodities chiefly in mind, but with the prices of human effort and sacrifice, and the prices of land, securities and other rights, always in the background. I shall also

consider only the movements of the *general average* of prices. Of course, wide movements of particular prices and price groups occur relative to this general average. movements which are diverse and often difficult to reduce to useful generalizations. But these *relative* movements can usually be accounted for fairly easily in each particular case: for example, in terms of crop failures, floods, the A.A.A., new tariffs, shifting styles and tastes, and the like. They do not present the most important problems.

If we look at the principal factors or forces which at one time or another have been thought to have a dominant influence on the general average levels of prices, we find that the list is long and diverse. The man in the street commonly gives the leading role to what he calls demand and supply. Then he stops, confident that he has said something. Clearly, however, he has only restated the problem. We need to know what demand and supply themselves are, and especially *why* they are what they are.

Others, with somewhat greater sophistication, talk wisely about gold as the villain in the piece. There is something in this view, obviously, but it can hardly be the whole story. In recent decades, gold has never been an important medium of exchange in this country, and at the present moment it is not in circulation at all. Its chief function has been to act as a reserve behind currency and bank deposits. But its actual reserve relation to currency, and especially to deposits, is both variable, and within wide limits unpredictable. We cannot say, for example, that increasing our gold reserve by one dollar will necessarily increase our bank deposits by ten dollars, or by twenty, or by any other unique amount. Depending on the circumstances at the time, the coefficient of increase may lie anywhere between zero and perhaps 30 or 35. Again, the Warren-Pearson theory about gold, which the Roosevelt Administration adopted in 1933, is hardly acceptable without elaborate modification. In its original form, it is naive in logic, and over the last three years has in largest part failed to work out empirically. This theory holds

that if you raise the price of gold in terms of currency by a given amount, all other commodity prices will rise in equal degree. So far as our prices have risen since the 1933 devaluation, the rise (except for an initial speculative boom) has been due almost entirely to other factors than the devaluation itself, at least in the first instance. The price of gold influences the price of other commodities, if at all, only indirectly and at several removes.

A third line of explanation, which was dominant among English economists for nearly a century before the World War, and which until recently was accepted by the great majority of American economists, looks to the quantity of the media of exchange actually in use. These media of exchange are now chiefly currency and bank deposits. The doctrine based upon their size was the so-called quantity theory of money, familiar to you all. This theory is one of the oldest elements in the existing body of economic ideas. As far as I know, it was first stated explicitly in 1568. In its most rigid form, it merely declares that changes in prices are proportional to changes in the quantity of money. This view too, obviously, has something to be said for it, especially with respect to very large changes in the money supply. But the most superficial inspection of the logic of the situation, and of the available statistical facts, shows that this also can be at best only a partial explanation. Even when allowance is made for the velocity of circulation of money, the relation of money to the levels of prices is variable, not unique, and is not at all closely predictable.

Then there are, fourth, a number of explanations of price levels and movements which run in terms of the particular types of organization and procedure through which men desire or permit their group economic activities to be conducted.[1] I have in mind here such diverse things as governmental and private monopolies, trade associations (not omitting the N.R.A. and the A.A.A.!); the complex of customary and legal

[1] I take it this is what some economists have chiefly in mind by the term "economic institutions," when they attempt to give that term a specific meaning. Private property, and the practise of observing contracts, are also "institutions" in this sense.

factors which makes some prices "sticky" or even virtually immovable, such as street car fares; government control of prices in war time; and the like. These factors clearly have an influence on price levels. In most cases, however, they are not responsible for *large and frequent changes* in the general aggregate of prices. It is these latter changes which seem to be especially disastrous to economic welfare, and the origins and control of which are therefore of especial interest to the economist. Similarly, wars and other catastrophes may produce great effects on prices at any one time, but are not a major factor in those frequent wide fluctuations in prices, which are so likely to be characteristic of even the most peaceful eras.

Finally, the monetary theory of the last ten or fifteen years has put especial stress on the shifting relations between the current volume of new saving and the current volume of new investment. These shifts are held to affect not only the prices of particular classes of commodities, but also the average prices of everything in general. Broadly speaking, it is argued, for example, that if the nation at any one time saves more than before, and if other things remain unchanged, then the nation necessarily spends less than before. Other things still equal, prices, business activity, and the aggregate of individual money incomes will then all fall. On the other hand, if investment increases, either through the spending of past savings or through the creation of new bank deposits for the purpose, prices and business activity will rise. These ideas have been developed, in various alternative and sometimes conflicting forms, by (in particular) D. M. Robertson, J. M. Keynes, F. A. Hayek, and their several followers.[1]

It is at once clear that the current relation of saving to investment must often, and perhaps usually, be an important factor governing the levels and the changes of prices. But here again one wonders whether this alone can possibly be the whole story. It seems self-evident that even if new saving and new investment both stood at zero, large and frequent

[1] With varying degrees of indebtedness, of course, to the economists of the late nineteenth and early twentieth centuries.

changes in prices could still take place—say, in consequence of changes in the quantity of money itself. Of course you can get around this contention, as some have already done, by so defining your terms that a change in the quantity of money is said to *be* an act of saving or an act of investment. Such a procedure seems of doubtful value, however, for it jumps over some of the most important problems we must actually deal with, and it ignores some of the most important effective factors in the situation. I am not clear that even Mr. Keynes' latest book, which seems to me a great improvement on its predecessors, fully escapes this defect, of solving certain problems by simple definition.

Thus the recent work in monetary theory, valuable though much of it is, does not give us completely satisfactory answers to the question of prices. Nor is it without significance that this recent work is almost entirely "theoretical," in the sense of being speculative. It proceeds deductively, from a few broad and largely untested premisses. Little attempt has been made, in this recent work, to build up an adequate body of knowledge from the systematic collection and analysis of empirical data.

In the face of this situation with respect to the doctrines and the data which lie to hand, can we reach any useful conclusions as to the factors which dominate prices and as to the control of these factors themselves? I think we can.

One thing seems clear at the outset. Prices are not related *directly* to any one of the other factors we have previously been considering, but are related only at one or more removes. The first effect of an increase in current investment, for example, is to increase *the total money volume of spending* (other things always equal). This latter increase may then work itself out solely in producing a rise in prices, or solely in producing an increase in the physical quantities of goods produced and sold, or it may do both. Most commonly, something of each possible result will appear. From the analytic point of view, however, at least one major step has intervened between the change in prices, if such a change

takes place, and that increase in current investment which was here the initial disturbance. The intervening step is the increase in the money volume of spending.

Now the question of whether an increase in the total volume of spending will produce a rise in prices, or a rise in the physical quantities of goods sold, or a rise in both, is significant; and the answer to it is complicated. This answer runs partly in terms of the working and the effects of such social and economic institutions as were referred to previously—monopolies, trade associations, customary prices, and the like. It also runs partly in terms of the technical coefficients of production, which govern the relations between changes in output and changes (other things equal) in unit costs. These various factors, however, ordinarily do not produce *large and frequent* changes in prices. For our present purposes, they are therefore of the second order of importance; and in a preliminary approach to the problem of prices, they can safely be ignored.

The factor of prime importance is, rather, changes in the total money volume of spending. This money volume is most easily measured, as a first approximation, in terms of the national money income. After allowance for changes in the degree of business integration and combination, and for changes in the current relation of investment to saving, the two apparently vary roughly in proportion. Now it so chances that I have just finished a study of the movements of the national money income in this country, during the quarter century from 1909 through 1932, and of some of the factors to which it is related. The results will appear as a chapter in a book I hope to publish within a few days, on *The Behavior of Money*.[1] For our purposes here, the most significant finding of that study is that changes in our national money income have been predominantly associated statistically with changes in the *total stock of money*, taking currency and demand deposits together. Changes in the circular velocity of the money stock, it is true, also contributed something to the

[1] McGraw-Hill Book Co., New York, 1936.

changes in the national money income. But their influence and effects were far smaller than those of the money stock; and until the beginning of the present depression, such changes in circular velocity were confined within relatively narrow limits (roughly plus or minus 11 per cent around a nearly horizontal trend).

The first major practical conclusion we reach, therefore, is that in order to do something about prices, we must begin by doing something about large changes in the stock of money.[1] Absolute fixity of the size of the money stock would probably be undesirable, for a number of reasons. But if we were to stabilize the quantity of money *per capita*, we should also come fairly close to stabilizing average money incomes per capita, and hence to stabilizing the total money volume of spending per capita. So far as fluctuations in general prices still remained, these fluctuations would then be due either to short-period changes in the circular flow of money, or to the effects of the institutional and technological factors previously mentioned. Moreover, there is good ground for thinking that these fluctuations would be far smaller and less frequent than those from which we now suffer. I am therefore disposed to advocate stabilizing the quantity of money per capita, in order to make prices behave in more desirable ways. I do not advance this suggestion on the ground that its adoption will lead to the millenium. But I do think that its adoption would produce a far more orderly, more equitable, and probably more prosperous economic life than any we have hitherto known.

Let me conclude by putting the whole argument in a nutshell, so far as concerns prices. (1) The factors which influence prices in important degree are numerous, complex, and of quite different orders. (2) Of these factors, the one the fluctuations of which seem, on the basis of the available evidence, to be by far the most closely associated with undesirable and even disastrous changes in the total money volume

[1] This conclusion, though of course it does not follow from the mere fact of statistical association, can be given extensive support on logical grounds.

of spending, and hence (at one remove) in prices, is the stock of money. (3) Stabilizing the stock of money per capita will not stabilize prices; but it will reduce the factors which alter prices to two main categories, neither of which is likely to produce *large and frequent* price fluctuations. One is the technical coefficients of production, which are progressively altered by the advance of technical knowledge. The other is the broad group of "institutional" factors. Of these two categories, the first is likely to operate to our advantage through time, rather than otherwise; and the second, if the nation as a whole so desires, is amenable to meliorative control. The unfettered maniac in our economic life today is frequent large changes in the money stock. The forging and fitting of adequate shackles is not a task beyond our powers.

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THE EXCAVATION OF ANTIOCH-ON-THE-ORONTES

CHARLES R. MOREY

(Read April 24, 1936)

ABSTRACT

The Committee for the Excavation of Antioch and Its Vicinity representing the Musées Nationaux de France, the Baltimore Museum of Art, the Worcester Art Museum, and Princeton University, is now directing its fifth campaign on the site.

The city founded in 300 B.C. as the capital of the Seleucid Kingdom of Syria had by the fourth century A.D. grown to a population estimated as high as eight hundred thousand, its extent being half again as large as Rome within its walls. Being the place of the first organization of the Church and the point of radiation of early Christian missions, it had become by the fourth and fifth centuries not only the cultural, political and military capital of the Near East, but also the focus of Eastern Christianity. The four campaigns of the excavation hitherto completed have naturally only initiated the uncovering of this vast site. The excavations have laid bare the circus, located the theatre at Antioch, completed the uncovering of the theatre at Daphne its suburb, recovered a long list of pieces of statuary and architectural fragments, a number of inscriptions, a Christian church of the type of Kalat-Siman, but dating in 384 A.D., about fifty years before the famous Church of St. Simeon, and have brought to light a large number of houses of Hellenistic and Imperial date. The outstanding category of objects found consists of nearly 250 pieces of mosaic pavements, of quality hitherto unmatched except by those in the Naples Museum, and covering a period from 100 A.D. to the 6th century, whereby it will be possible in the near future to write the missing chapter in the history of late antique painting of the Near East.

Antioch [1] was founded in 300 B.C. The city which Seleucus Nicator established had a conglomerate population made up of native Syrians, Greek settlers already on the site in a village called Iopolis, and the transplanted inhabitants of the short-lived colony of Antigoneia which Seleucus' rival Antigonus had founded six years before at the bend of the Orontes. It may be considered certain from a process of exclusion of the later enlargements of the city that Seleucus' town lay along the east bank of the Orontes and extended to the south branch of the Island in that river (Fig. 1).

[1] The excavation of Antioch was commenced in 1932 under a five-year concession from the Government of the Syrian Republic. By the terms of the concession the immediate direction of the excavation is entrusted to Princeton University. The field-staff during the last season consisted of Prof. W. A. Campbell of Wellesley, field-director; Jean Lassus, assistant field-director; Donald Wilber, architect; Miss Margaret Surré, assistant architect; Miss Gladys Baker, cataloguer and numismatist; W. H. Noble, cataloguer; George Reynolds, assistant.

The first enlargement was made according to Strabo by "a multitude of settlers," and again by a process of elimination this may be regarded as no more than an extension of the

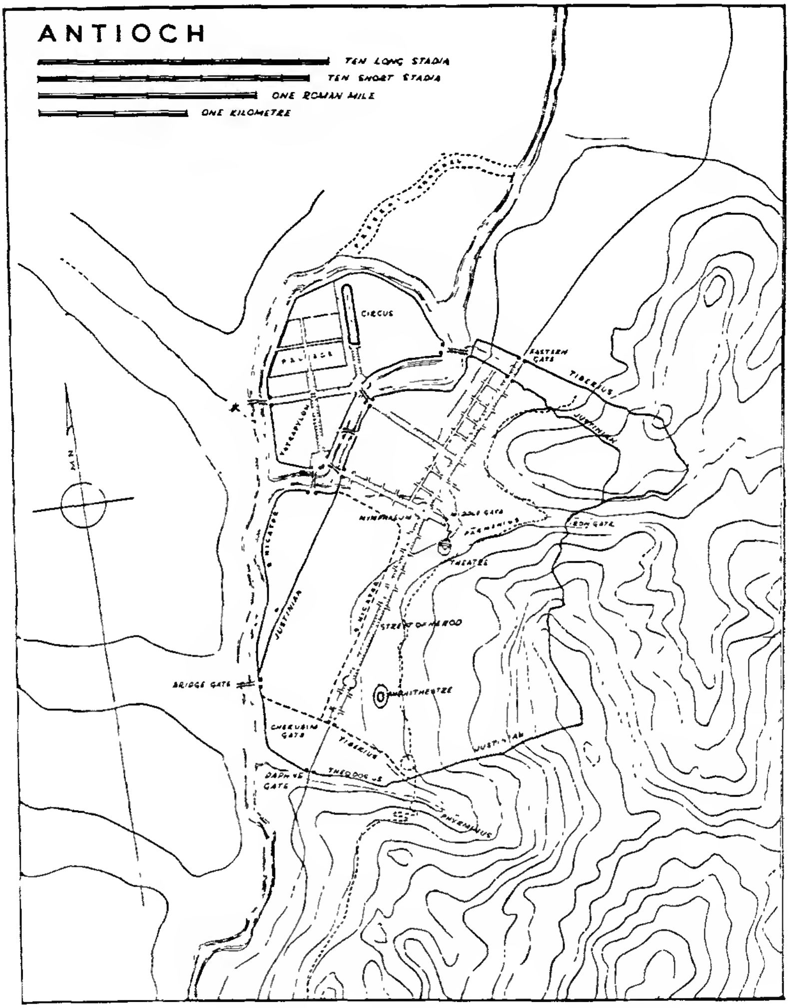


Fig. 1. Restored plan of the principal arteries of the ancient city.

confines of the city to the east, to the point where the spur of Mt. Silpius approaches the river. The next extension was the settlement of the Island in the Orontes, begun apparently by

Seleucus II Callinicus (246–226 B.C.) and completed by Antiochus III the Great (223–187). The battle of Magnesia in 189 B.C., which lopped off from the Seleucid realm its prized sovereignty over Asia Minor, not only made Antioch instead of Ephesus thence forward the definitive capital of the kingdom, but left the defeated Antiochus with large contingents of Greek mercenaries to take care of, whom he forthwith established on the Island in the neighborhood of his own royal residence there, and thus constituted the third of the future four quarters of the city which merited Antioch the title *tetrapolis* that she was given by Strabo.

This Island in the Orontes has now disappeared. It has been variously located and defined in previous attempts to reconstruct the topography of the city, but it was not until the season of 1934 that Wilber succeeded in surveying the line of the ancient southern bend of the Orontes, and delimiting the Island throughout nearly all of its extent (Fig. 2). We know from our sources that five bridges connected the Island with the east bank of the river; the bridge-head of one of these was discovered during the campaign of 1934, and its location on axis with the Circus makes it clear that the two were connected by a street which actually came to light last season. This bridge-head was also a gate, still called at the present day by the natives with its ancient name of Bab el Kelb, the "Gate of the Dog." The Circus, the earliest Roman contribution to the monumental development of Antioch, having been built in its original form by Q. Marcius Rex, pro-counsul of Cilicia, in the first century B.C., is the only monument that was visible above ground when the excavations began. Its location on the Island, and therefore in proximity to the *regia*, is interesting in connection with Dio Cassius' account of the adventure of Trajan during the great earthquake of 115, in which, Dio relates, "Trajan made his way out through a window of the room in which he was staying. Some being, of greater than human stature, had come to him and led him forth, so that he escaped with only a few slight injuries; and as the shocks continued over

several days, he lived out of doors in the hippodrome." Since the royal palace was presumably Trajan's residence, its proximity to the Circus on the island gives topographic color to Dio's account.

We know something of the surroundings of the *regia*, if not of itself. "At the so-called *tetrapylon* of the elephants near the *regia*," says the Antiochene chronicler Malalas of the sixth century, the Emperor Julian the Apostate, who spent an unhappy eight months in Antioch in 362–3, published his *Misopogon*, a bitter diatribe on the people of the city in retaliation for their freely expressed distaste for himself. This tetrapylon was destroyed in the earthquake of 458, together with the "colonnades before the palace" (Evagrius II, 12), and also the towers at the gate of the hippodrome, with some of the colonnades that led to them. From this we deduce the colonnaded street leading south from the palace, and the tetrapylon where it was crossed by another at right angles, and also the colonnaded street leading from the Circus to the bridge-head mentioned above. We know also from a passage in Theodoret (IV, 26, 1–3) that a road ran between the palace and river, and that on the city wall which followed its course there was a lofty stoa.

It was on this island-area that the excavations of 1932 and 1933 were mainly conducted, and one of the five baths discovered during these digs, Bath *C*, is certainly worthy by size and elaboration to form part of the palace-complex. The fifth bath (*E*) was uncovered northeast of the Circus: it was this which yielded the remarkable mosaic (Fig. 3) of the Earth-mother giving birth to the Crops which so closely corresponds to the picture described by Johannes of Gaza (VI century), which picture is ambiguously noted by *marginalia* in the manuscripts as existing in "the winter bath at Gaza—or in Antioch."

If Callinicus' extension was laid out in the customary gridiron of Hellenistic city-planning, we may assume that the street which must have led to the bridge-head discovered in 1934, joined the main street at right angles. The course of

this main street has been determined with a fair degree of certainty by the excavations of 1934 carried on at different points of the main street of the modern town. These showed that the ancient street followed the line of the modern one, though slightly to the east of it, up to the point where it is crossed by the torrent Parmenios, where the ancient street continued with less deviation to the east than is the case with the modern road, to end in two gates at the north end of the old city—one the Gate of St. Paul in the Justinian wall, and the other somewhat further northeast, located by Wilber in what was an earlier *enceinte* of the city before its fortifications were reduced in radius by Justinian in the sixth century.

This earlier gate may have been the "eastern gate" which Malalas says that Tiberius built, and put a Roman stamp upon the work by erecting above it a stone group of the Wolf and Twins. Another gate, the "Middle Gate," is attributed by Malalas to Trajan, and he says that this also was adorned with a group of the Wolf and Twins. The Middle Gate we know must have stood at the foot of Mt. Silpius where the torrent Parmenios flows into the plain, for it was near the Temple of Ares, which in turn was part of the complex of plazas and buildings that clustered about the forum which Valens built over the lower course of Parmenios.

The location of the Middle Gate determines the position of the cross-street that bisected the main street of Antioch, and must have ended in one of the five bridges connecting the city with the Island. The plaza which marked the crossing can be reconstructed to some extent by a description in Libanius which gives us an impression of a colonnaded half-circle (*nymphesum*) that formed a monumental entrance to the cross-street. It is also the most likely spot wherein to locate the statue of Tiberius which the senate and people of Antioch set up in his honor "in the open space between the colonnades." This statue which stood on a "great Theban column" has been identified by Lassus with the figure standing on a column that appears in the border of a mosaic discovered in Daphne in the winter of 1932–3, which border is

a sort of pictorial sight-seeing tour through Anticoh and its suburb Daphne. The mosaic can be dated. On one side is a representation (Fig. 4) of the Olympic stadium at Daphne and of a building labelled τὸ πρίβατον Ἀρδαβουρίου, which can be reasonably regarded as belonging to or built by the official of that name who was *magister militum* at Antioch between 451 and 466–7. On the other hand the stadium was almost certainly ruined beyond repair, like the Circus at Antioch, by the earthquakes of 526 and 528, and the games were suppressed in 520. Our border thus dates in the latter half of the V century or the early years of the sixth. In the course of the topographical tour that one experiences in following the series of buildings, shops, street-scenes, etc. that composes the mosaic, a column is encountered with a statue on its top in the customary walking pose of an Emperor of the Augustan era, with the inscription . . . PIANA, inviting Lassus' restoration ἡ στήλη Τιβηριανά (Fig. 5).

Tiberius, says Malalas, built "outside the city two great porticoes near the mountain which is called Silpius, with lengths of four miles . . . and he joined with this wall the new to the old wall of the city which had been built by Seleucus, shutting in with his own wall both the acropolis and Iopolis." "Outside the city" means that the new stoas were built between Seleucus' city and the mountain, and the new city wall of Tiberius was evidently built to inclose the mountain slopes which left the city unguarded to the east. For under Antiochus IV Epiphanes the city had been extended up the mountain slopes, adding the fourth quarter to Antioch which brought it Strabo's appellation of *tetrapolis*, but this quarter, until the time of Tiberius, had not been inclosed in a wall. From further details in Malalas we learn that Tiberius' porticoes bordered a street, with *tetrapyla* at the points where the side-streets branched off from it. One of these points may probably be identified with the small circular plaza excavated in part by Lassus in 1932. The center of the street must have been left unpaved; at any rate Caracalla is said by Malalas to have "executed the paving of the street of

the great porticoes built by Tiberius." What was the relation of Tiberius' colonnaded street to that which Josephus and Malalas tell us was paved and lined with porticoes by Herod in the time of Augustus, is not yet clear.

From a hitherto unused source, the older Life of St. Simeon the Younger, R. E. G. Downey has gathered the important information that the western or southern gate in Tiberius' wall was the place "of the Cherubim," where Titus set up "before the gate of the city" the bronze Cherubim which Titus found in the temple at Jerusalem. From the same source Downey has located the Kerateion, the Jewish quarter of Antioch, in the district outside the Cherubim gate. Under Theodosius I or II this district was inclosed in the *enceinte* of the city by a wall which was incorporated later in the circuit of Justinian, and pierced by a gate known as the Daphnetic or "Golden" gate, since from it issued the road to Daphne, five miles away in the hills to the southwest.

So much the excavations, and the labors of Downey, Friend and Wilber in the archæological laboratory at Princeton this winter, have reconstructed of the topography of Antioch. It discloses a city-plan which in its ensemble is the Roman, not the Hellenistic city, and indeed the objective of this expedition must ever be mainly the reconstruction of Antioch as Antioch the Great, the capital of the Near East in late antiquity, ranking with Rome, Constantinople, and Alexandria as one of the four metropoles of Diocletian's reorganized empire. As a mobilization-point for the Roman armies engaged in the perennial campaigns in Mesopotamia, it was an object of constant solicitude by emperors who dared not face the danger of a disgruntled populace. Their munificence begins with Cæsar whose basilica, the" Kaisarion," was retained as part of the complex surrounding the Forum of Valens (Fig. 4). He built the theatre, the site of which, south of Valens' forum, was discovered last year. Agrippa added a storey to the theatre, and built the baths called the "Agrippianon." Tiberius, in addition to the monumental gifts already noted, added still another storey to the theatre,

built a temple of Zeus and a sanctuary of Dionysos and Pan. Vespasian and Titus are said to have destroyed a Jewish synagogue in Daphne and replaced it with the theatre of which the excavation was completed during the season just past (Fig. 6). Domitian contributed baths and a temple of Asclepius. Trajan, grateful for his escape from the earthquake of 115, set up a temple to Zeus in Daphne. Hadrian visited the city more than once, and insured its water supply by one of the great aqueducts from Daphne, the course of which was surveyed by Wilber last year; to Hadrian was ascribed by Malalas the *theatron* of the springs of Daphne which appears on the topographical mosaic of Daphne under the personification of *Kastalia*. The city received gifts of buildings from Marcus Aurelius and Septimius Severus. Caracalla's paving of Tiberius' colonnaded street has already been mentioned. Diocletian, who favored Rome with but one great monument—the Thermæ on the Quiririal—, built at Antioch two palaces, one at Daphne and the other in the city; a bath near the Circus which may well be the "winter" Bath *E* of which the pavement has preserved the mosaic of the Earth and her Crops (Fig. 3); three other baths; a stadium; a temple to Zeus; a temple to Nemesis. He restored the temple of Apollo, and built a shrine of Hecate in a grotto with 365 steps leading down to the sanctuary. He erected arsenals, granaries, and restored the mint.

In the fourth century imperial munificence continues the lavishness of Diocletian. With Constantine the city was definitely enthroned as the capital of the Near East by the establishment there of the residence of the *Comes Orientis*, and its metropolitan status in the Eastern church was confirmed by the erection of the *Domus Aurea*, the great octagonal church of which the location and excavation are a cherished objective of our expedition. The city was the residence as well, for considerable periods, of Constantius, of the Cæsar Gallus, of Julian. Valens built his forum with its basilicas (Fig. 4), and baths. Theodosius the Great, who never visited the city, nevertheless built for it basilicas, baths, and streets.

Reminiscence of such imperial favor is found in the portrait busts that were included in a miscellaneous *cache* of statuary, of the late third century, and the beginning of the fourth, which was exhumed in the courtyard of the barracks (Fig. 7). One of these is a fine imperial portrait, perhaps of Gordianus III who was murdered (A.D. 244) while leading his troops down the Euphrates against the Persians. The revolt in which he was slain by his own troops was without much doubt instigated by his successor Philip the Arabian. Philip had some interest in Christianity, and the story that Babylas, bishop of Antioch at the time, refused an emperor admittance into his church may well apply to this imperial criminal. Babylas was martyred according to Eusebius in the persecution of Decius in 250; his body, buried at first in the city, was later interred by the Cæsar Gallus at Daphne where its presence so inhibited the responses of the oracle in the Apollo temple, according to the Emperor Julian, that the latter moved the martyr's bones back to the city. Somewhat later they were installed with great ceremony in a *martyrion* outside the walls across the river, in a region in fact where the excavations of the past season uncovered a cruciform *martyrion* of four naves radiating from a central open court in which are remains that might be those of the martyr's tomb or shrine the whole being dated by mosaic inscriptions in the year 387 A.D.

The sovereign position of Antioch in the fourth and fifth centuries of our era is nowhere better visualized than in the *Tabula Peutingeriana* of Vienna, a XII–XIII century copy of an antique map that gives us a strangely effective notion of the relative importance of the cities of the empire (Fig. 8). For in this map only Rome, Constantinople, and Antioch are honored by the representation of their "Tyches," or personifications, enthroned upon the perspective view of the city, and over all the Near East the figure of Antioch, seated on Mt. Silpius with the personified Orontes at her feet, stands out in this map as the recognized metropolis. We detect her preeminence more clearly perhaps in the imitation of her art in the provincial towns of the Near East—in ruder copies of her

architectural monuments, detected by Wilber from a comparison of cornice-blocks of Baalbek and Jerash with one recovered during the excavation of the theatre at Daphne (Fig. 9); in the frank copy, for the "Tyche" of Dura on the Euphrates, of the great statue of Antioch's Tyche done by Eutychides the pupil of Lysippus for Seleucus Nicator. The picture of the Earth and her Crops described by Johannes of Gaza in the sixth century, and so closely repeating the details of the pavement of Bath *E* (Fig. 3), may be a case of the same sort.

The city was in fact the focus wherein were joined the cultural currents of East and West; of Latin and Greek culture on the one hand, and the traditions of Semitic Arabia, Palestine, and Mesopotamia, together with those of Persian Iran, on the other. Of the two great Hellenistic outposts which the conquest of Alexander left upon the Oriental frontier—Alexandria and Antioch—the latter was far more effective as a transmitter of Oriental influence to the Greco-roman world of the Mediterranean. Alexandria, brilliant exponent though she was of Hellenistic civilization, was never more than a Greek oasis in the traditional culture of Egypt. But Antioch throughout her history was hard pressed to maintain her Greek traditions against the Oriental prepossessions of most of her new population, and of the Eastern lands over which she claimed cultural leadership. Evidence of this may be found in the persistent and artificial attempts to reproduce Hellenic concepts: the establishment of the Olympic games; the wholly manufactured myth of Apollo and Daphne; the delighted gratitude of the Antiochenes when the Empress Eudocia, Athenian by birth, pausing at Antioch on a pilgrimage to Jerusalem (444), addressed the populace in the Senate-house and quoted Homer with the flattering phrase, "from your race and blood do I claim descent." A golden statue of the tactful Empress was forthwith set up in the Senate-house.

So it is that while the contribution of Alexandria to late antiquity was almost wholly Hellenistic in form and content,

that of Antioch was predominantly the re-casting of the native concepts of the Near East in Hellenistic form. The most obvious example of this is Christianity itself, which began its missions not from Jerusalem, but from Antioch where the Christian name was first coined. It was the predominant element of Gentiles in the church first organized at Antioch that liberated the faith from its Jewish limitations and sent it forth to conquer the Mediterranean world. Paul set forth from Antioch on his missions; Luke was by a tradition as old as the III century, a native of the city. The Antiochene schools that grew up after the peace of the Church were the sturdiest opponents of the theology of Alexandria; to the latter's efforts to reconcile by allegory the rationalism of Greek philosophy with Scripture, the schools of Antioch opposed a literal and historical interpretation, and forced this view eventually into mediæval Christianity. Theodore of Mopsuestia, leader of Antiochene theologians in the fourth century, conceived the world for instance as flat, and the rising and setting of the sun as caused by its passing behind a lofty mountain in the north, which notion was further developed by the addition of a two-storied heaven, completing thus a universe the form of which was reproduced, according to Antiochene thinking, in the Ark of the Covenant. This was in opposition to the round earth of Alexandrian astronomy, and is a mile-post of that steady departure from the Hellenistic reign of reason in the Oriental direction of revealed sanctions. The substitution of Oriental religious values for the Hellenic material ones is as good a way as any of describing the profound alteration of the Mediterranean point-of-view during the first six centuries A.D.

We have hitherto been able to see the results of this process, but not to follow very clearly the process itself. Comparing the written thoughts of men in the sixth century, and what they built and carved and painted, with the corresponding phenomena at the opening of the Christian era, we realize that the outlook has shifted to a degree almost unparalleled in any other period of history. The transformation may be

described as a loosening of the old Greek grip on actuality, and the growth instead of a symbolic view of the physical world. In art the change is plain—the third dimension which still made things real in the first century A.D. had vanished by the sixth century. The rational composition wherewith Greek art organized the details of a subject around a central axis or motif was replaced by the time the sixth century arrived with an Oriental unending sequence of equal accents of which the only principle of unity was rhythm.

The stages of this process have now been revealed in the extraordinary series of mosaic floors, of which nearly 250 pieces have been raised and stored, which the excavations of the past four years have uncovered. The series begins with the triclinium floor found in a house of c. 100 A.D. on the Island, of which the central panel, representing the Judgment of Paris, is now in the Louvre, the oblong panel with the Symposium of Hercules and Bacchus is in the Worcester Art Museum, and the two dancing figures of a Satyr and a Bacchante, in the Museum of Art at Baltimore. The Judgment of Paris (Fig. 10) is a typical landscape of the type that flourished in the Hellenistic cities, with impressionistically modelled figures, a casual composition, and depth of space whose middle distance is marked by the stele surrounded by trees which is rarely absent from these idyllic pictures. Up on the slopes of Mt. Stauris, the north spur of Silpius, the mosaic crew last season raised a series of mosaics of the II century and early III which show the first signs of the disintegration of this Hellenistic naturalism (Fig. 11). The panel of Oceanus, for example, depicts a male torso fully modelled and boldly three-dimensional, but surrounded by fishes (so accurately done as to be an excellent catalogue of Mediterranean species) that are isolated one from the other in an arrangement that is already approaching the rhythmic. The same disintegrated composition is seen in the charming floor discovered outside the East Gate (Fig. 12) which shows us various playful occupations of putti, and their unhappy capture at the hands of a peddler who puts them in a cage,

all strewn about in defiance of Hellenistic unity. In a third-century villa in Daphne there was found a magnificent panel representing Field and Fruit as two figures banqueting, served by a Satyr-like figure of Wine (Fig. 13). Here the background is a wall, confining the action to a plane of two dimensions. A panel showing Hermes carrying the infant Dionysos to the Nymphs (Fig. 14) discovered on the Island in 1933, carries the process a step further—the disintegration that was hitherto only visible in composition, has here attacked the figure as well, and torso and limbs are put together as separate and unarticulated parts. The movement is confined to a plane; of background there is none; the cast shadow has already become an unnatural convention. This piece dates in the IV century; an echo of Hellenistic naturalism still lingers in the finest work of this century so far found at Antioch—the large pavement of the time of Constantine unearthed last season in Daphne (Fig. 15). Here we find again our landscapes—stele, trees and all—and modelled figures. But the hand of convention is already heavy on these delightful vignettes: the movement is stiff and unreal, the landscape without atmosphere, and the figures without shadow.

If we move from the fourth to the fifth century, the new ideal is frankly manifested. No longer do the mosaicists build up their pavements in separate panels in order to keep the Hellenistic unity of centralized composition by reducing the field to be composed. Instead they introduce the *Streumuster*, scattering groups of hunters and wild beasts over the surface with no thought of spatial relation, or boldly forsaking Hellenistic tradition altogether to have recourse to the Oriental carpet-pattern of a surface dotted with floral motifs in regular and rhythmic sequence (Fig. 16). Such a pavement is the Phœnix mosaic, so-called from its surprising central motif of the nimbed Phœnix standing on its mountain. The border too conforms to the new principle of rhythmic composition, consisting of a row of ram's heads which give unmistakable evidence of the Iranian origin of this new style

of decoration, since these winged ram's heads are a familiar motif on Sassanian seals (Fig. 17). Even when the borders of these mosaic carpets resort to renderings of birds and beasts that are portrayed with extraordinary verity (Fig. 18), the artist is following the Persian principle of naturalistic detail in a purely decorative composition, for he frames his life-like creatures in the rhythmic progress of vine-rinceaux, with no existence in space or relation of one to the other. The flexibility of the new Oriental decorative method, far more adaptable than the symmetrical Greek composition to areas of varied shape and size, is illustrated by the pavement of a large vestibule in a house at Daphne (Fig. 19) which portrays a series of five pairs of animals, each pair consisting of a wild beast and its prey, standing on either side of a tree the leaves and fruit of which are descriptively exact in detail and correspondingly unreal in ensemble. Such trees and their fruits will be found two centuries later in the mosaics which the descendants of the Antiochene craftsman laid on the walls of the Ommayad mosque at Damascus.

These masterpieces of mosaic art were made for the rich villas on the hills of Daphne, where the wealthier class lived for the sake of the springs and breezes, and the view down the valley toward the sea (Fig. 20). They were laid down not many years before the terrible earthquake of 526, from which Antioch never really recovered. The Persian raid of 540 completed the ruin caused by the earthquake, and when Justinian restored the city and renewed its walls, the circuit of the latter was drawn in to inclose a much diminished Antioch.

Before the earthquake we may reasonably suppose that the estimate made by some of a population of 800,000 is not exaggerated. Chrysostom in the IV century stated that Antioch contained 200,000 citizens; the addition of children and slaves to this number would confirm the figure given above. But after Justinian's time, and particularly after the Muslim conquest of the VII century, the glory of Antioch was no more. It shared the lot of the rest of the Greco-

Roman cities of the Near East on which the Arab blight fell, and dwindled through the centuries to so low a point of importance that its present population of 35,000 represents a recent prosperous increase.

Of the four metropoles of the later Empire it is the only one that can be excavated over nearly the whole of its area. Rome, Constantinople, and Alexandria are still populous cities where digging can only be sporadic and limited to minute areas. But Antioch of today covers only a fraction of the far-flung ancient city, and the excavations have revealed that only half of the small area of the modern town covers any inhabited portion of ancient Antioch. The opportunity of revealing the whole of one of the greatest of ancient cities, and the one that can tell us the most of late antique art and culture, lies here at hand. The area is vast, and only a fraction has been explored in the four seasons of our dig. But its very vastness imposes the sense of its significance, and the necessity of its full interrogation, in order that this great buried treasure of information on the most vital period of Mediterranean history may be reclaimed.

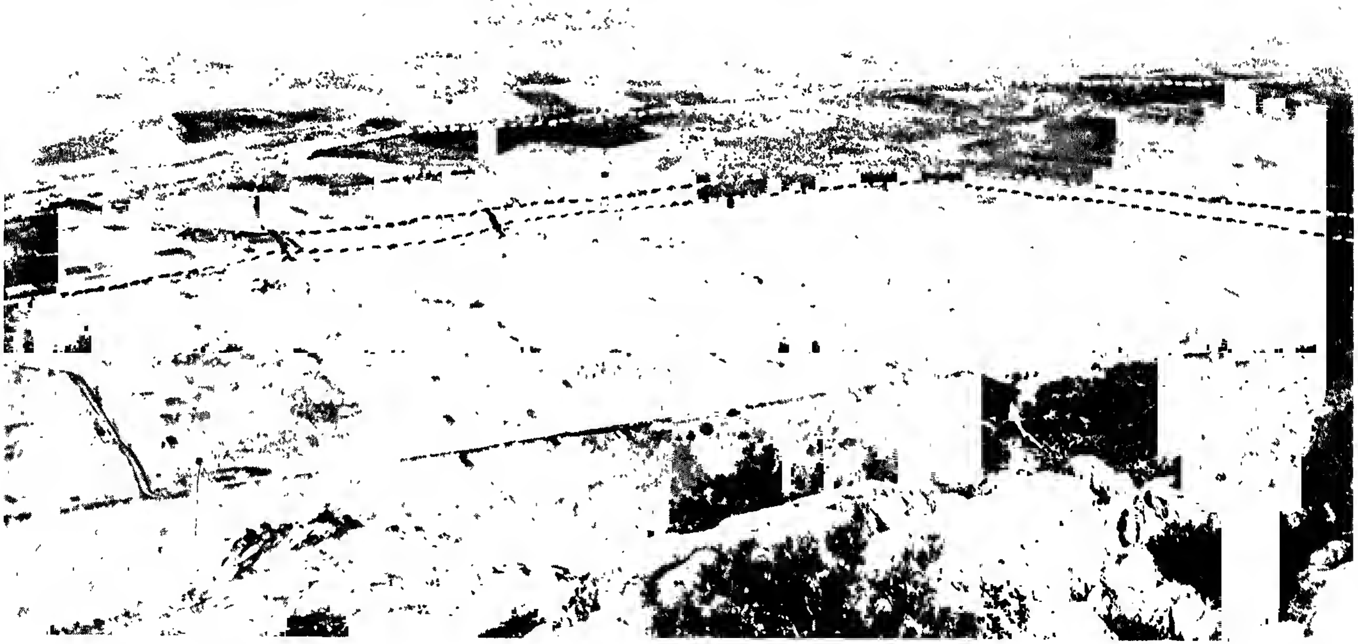


FIG. 2. View from Mt. Silpius showing bed of original east branch of Orontes and the Island.

PLATE II

FIG. 3. Mother Earth and her Crops. Mosaic from Beth A.

FIG. 4. Mosaic of the V century showing the Olympic Stadium and the Villa (?) of Ardeburius at Daphne.

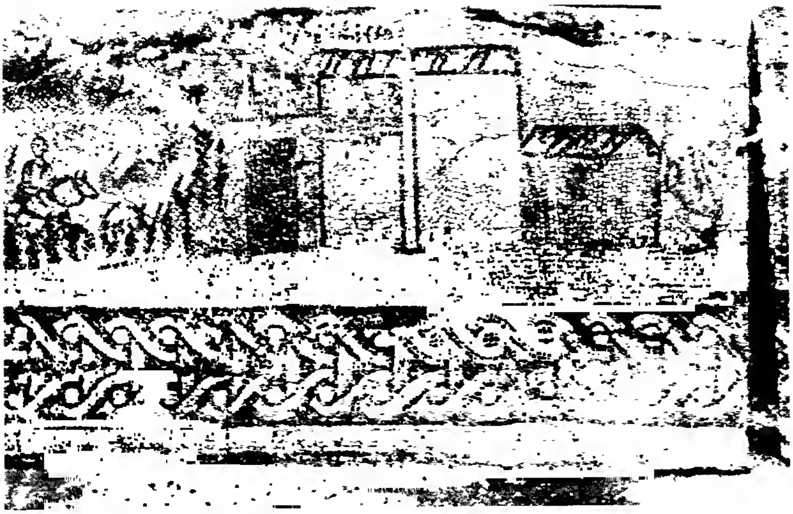


FIG. 5. The Statue of Tiberius—detail from the mosaic of Fig. 4.

FIG. 6. Satyr from a group of Satyr and Nymph, found in the theatre at Daphne.

FIG. 7. A philosopher, an emperor, and Gordianus III: busts found in the courtyard of the military barrack at Antioch.

PLATE V

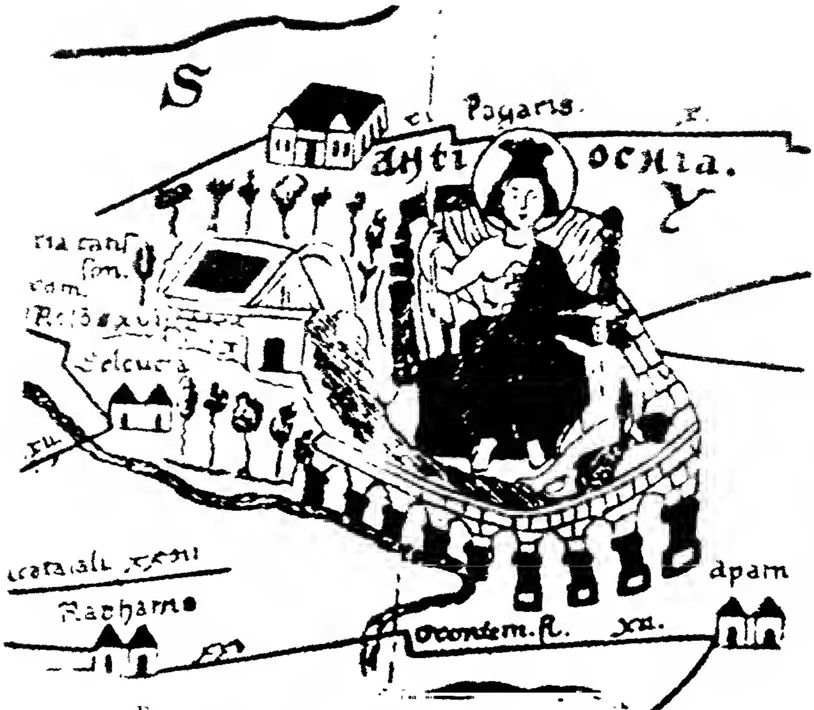


Fig. 8. The City of Antioch on the Peutinger map.

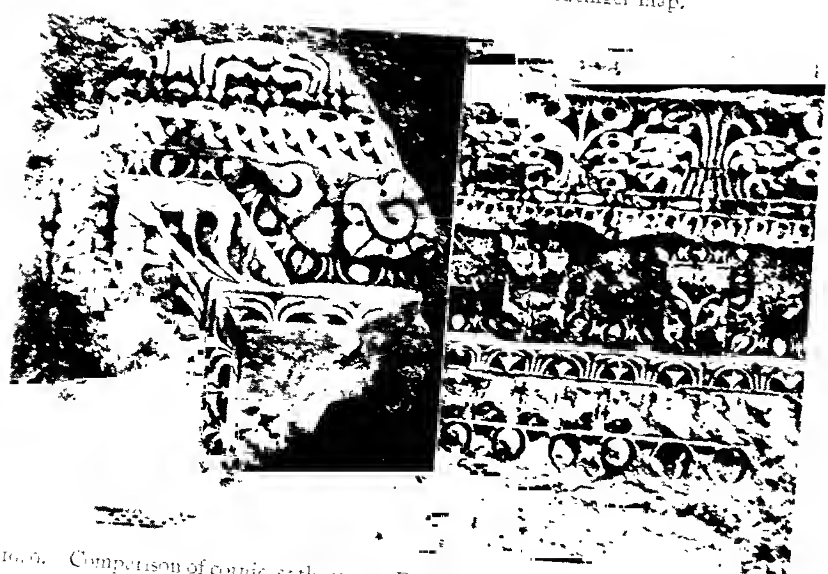


Fig. 9. Comparison of cornices: theatre at Daphne (left) and court at Baalbek (right).

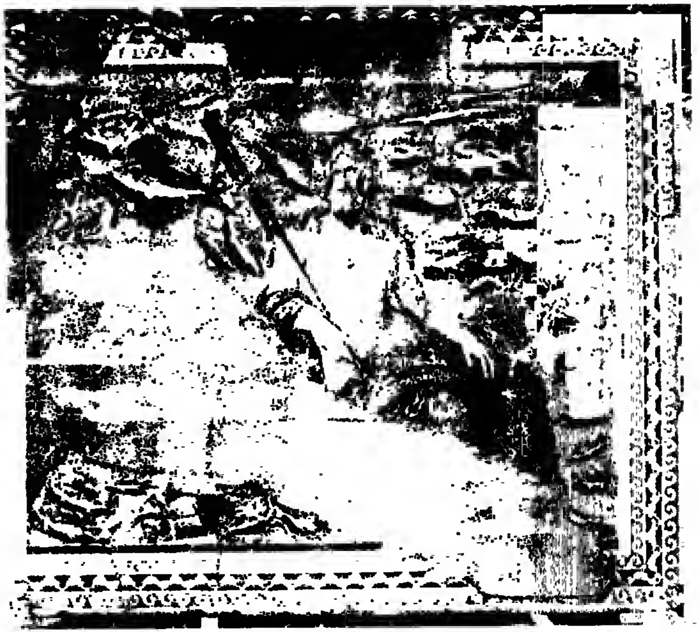


Fig. 11. Oceanus mosaic of the II century

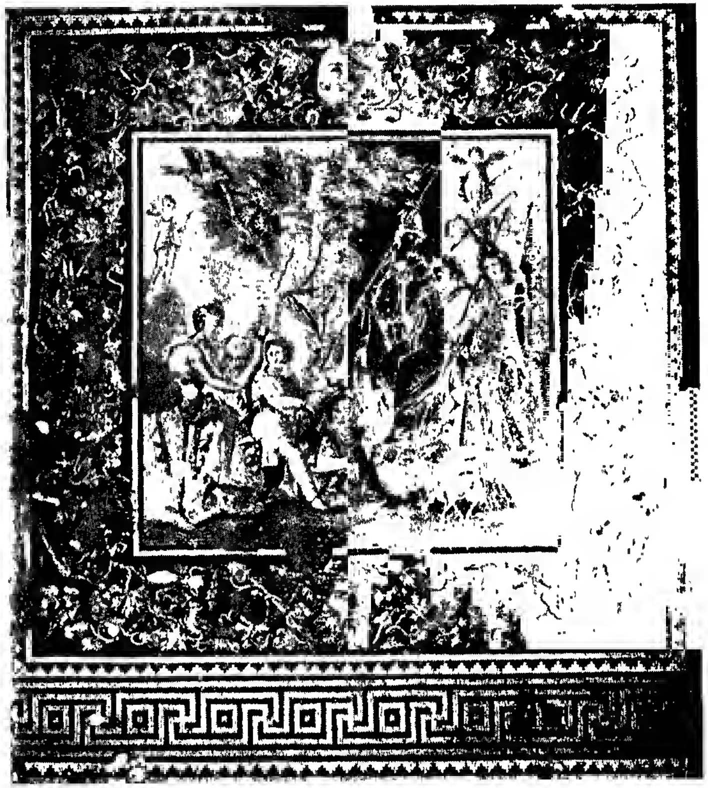


Fig. 10 The Judgment of Paris mosaic, now in the Louvre, discovered on the Island in 1932 Date c. 100 A.D.

FIG. 12. Cupids at play, captured, and caged by a peddler—mosaic of c. 200

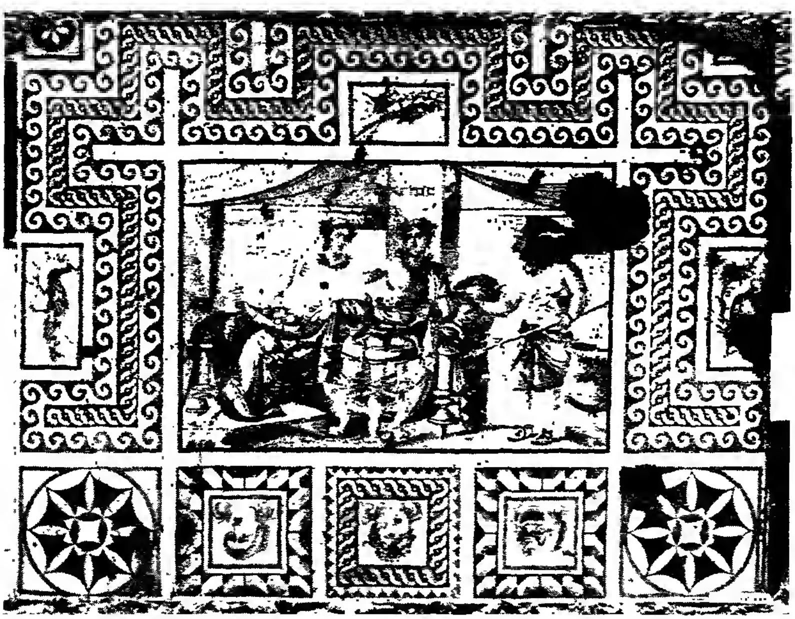


FIG. 13. Field, Fruit and Wine, at banquet—mosaic of the III century from a villa at Daphne.

Fig. 14. Hermes and Dionysos—mosaic of the IV century from Bath *D*, on the island

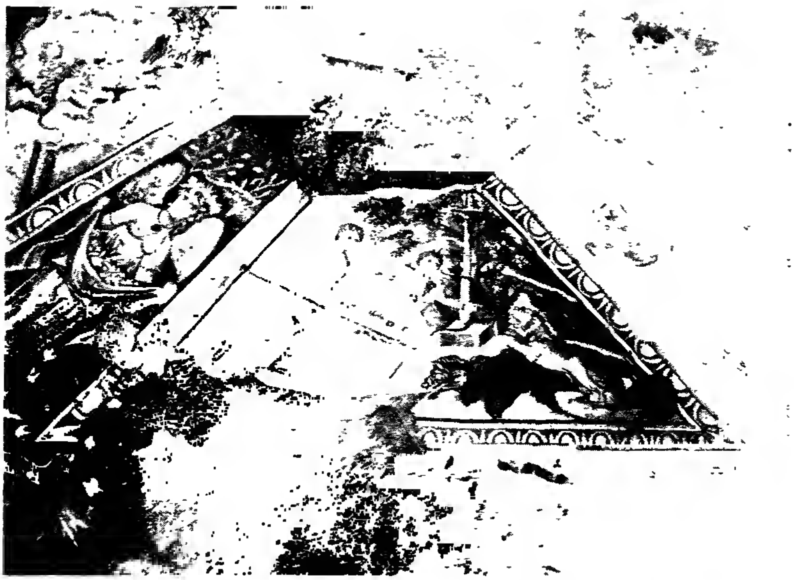
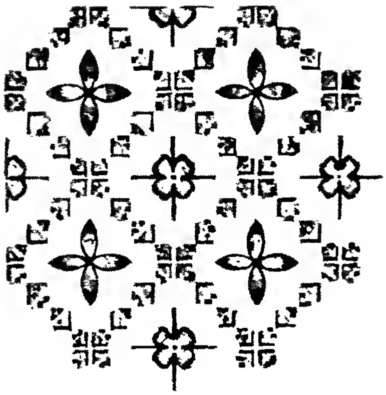


Fig. 15. Mosaic pavement of the time of Constantine, found at Daphne—detail



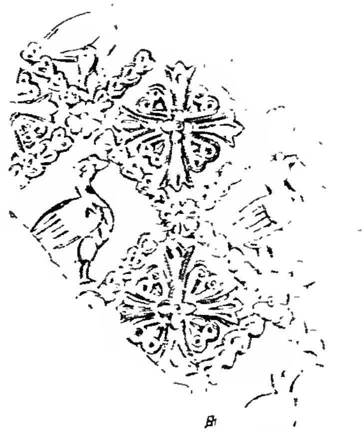


Abb 38. Stoff Nr. 15, nat Gr.

FIG. 16. "Carpet" pattern of Antiochene mosaic of V century, compared with a Sassanian textile.

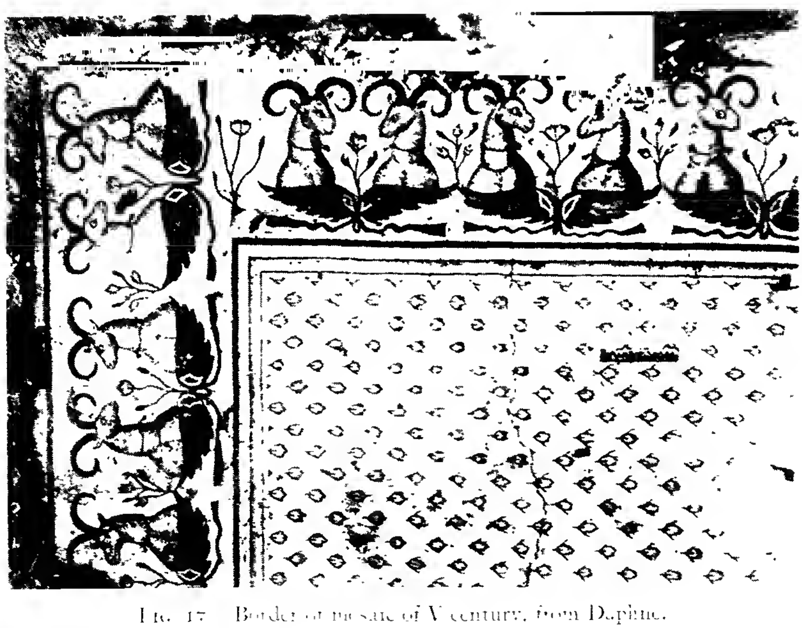


FIG. 17. Border of mosaic of V century, from Daphne.

PLATE X

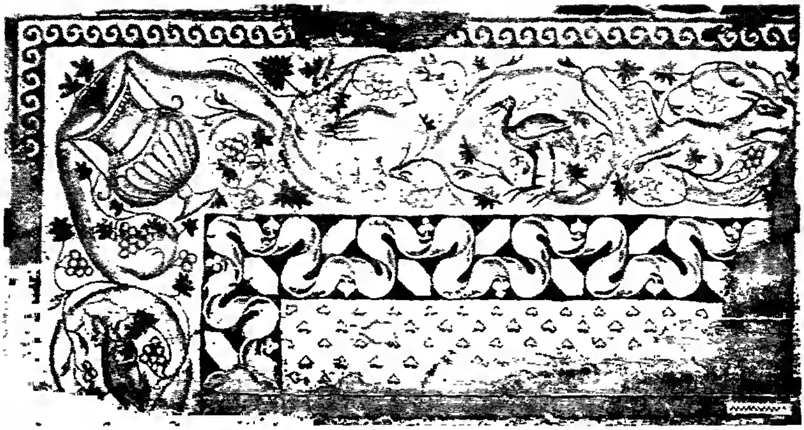


FIG. 18. Border of a "carpet" mosaic.

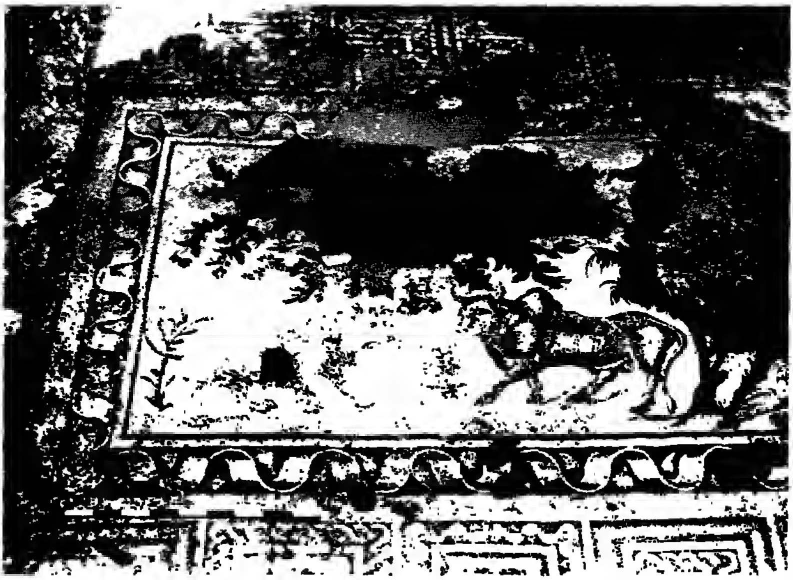


FIG. 19. Lion and buffalo—mosaic of the V century at Daphne.

PLATE XI

Fig. 20. Antioch and the Valley of the Orontes.

THE MECHANISM AND PATHOLOGY OF SHOCK

VIRGIL H. MOON

(*Read April 23, 1936*)

Abstract

Shock is defined in physiologic terms as a circulatory deficiency, not cardiac nor vaso-motor in origin, characterized by decreased blood volume, decreased cardiac output, and increased concentration of the blood. Decreased blood pressure, metabolism, temperature and renal excretion are regularly associated. Extreme weakness, air hunger, cold skin, rapid pulse and failing circulation are prominent clinical features.

Modifications of methods and observations on tissue pathology have obviated sources of error in previous investigations, and have furnished additional evidence. Both major and minor degrees of shock were produced, and observations were made during extended periods of time. The tissue changes distinctive of shock include marked engorgment of the capillaries and venules in mucous and serous surfaces, in the lungs, liver and kidneys; marked edema of lungs and mucosæ, and effusions of fluid into serous cavities.

Shock may be produced by various intoxicating agents. These include substances derived from injured tissues as muscle substance, burns, and intestinal obstruction, the injection of tissue extracts, histamine, bile, poisonous drugs, or of bacteria or bacterial products. These findings corroborate the conception of "traumatic toxemia" advanced by earlier investigators.

When affected by various toxic agents the capillaries and venules: (1) become atonic and dilated; this increases the volume-capacity of the vascular system (2) The capillary walls become abnormally permeable and allow the leakage of plasma from the blood into the tissue spaces. Such leakage produces edema, reduces the blood volume, and leaves the blood abnormally concentrated.

When death by shock was delayed 24 hours or longer, pulmonary edema occurred regularly. The edema fluid resembled blood plasma in its composition. When the animals lived several days a type of terminal pneumonia seen frequently in man, developed regularly. Each of these results is etiologically related to the mechanism by which shock develops.

Shock may be defined in physiologic terms as a circulatory deficiency, not cardiac nor vaso-motor in origin, characterized by decreased blood volume, decreased cardiac output and increased concentration of the blood. Regularly the blood pressure, metabolic rate, temperature and renal excretion are markedly decreased. Extreme weakness, air hunger, rapid feeble pulse, cold pallid skin and failing circulation are prominent features seen clinically. This condition, developing some hours after extensive injury to tissues but not involving any vital organ, has remained an enigma to medical scientists.

It frequently develops following extensive battle injuries or after complicated surgical procedures. It is seen following superficial burns, poisoning with various drugs, in toxemias of metabolic origin and in infections of unusual severity. This varied occurrence of shock has baffled explanation. What common factor can be found in conditions so diverse and what is the operative mechanism of that factor?

During the World War a special committee appointed by the British Government made a coördinated investigation of all phases of shock. The committee consisted of twelve English and American medical scientists of international distinction. Battle casualties in field hospitals and clearing stations provided abundant material for study. Investigations lasting more than a year were made on wounded soldiers and on shock produced experimentally in animals. The reports (1) of this committee supplied the physiologic data incorporated in our definition for shock. They indicated that it results from toxic substances absorbed into the circulation from areas of damaged tissue. It was shown (Dale, Laidlaw, Richards (2)) that histamine, a substance present in small amounts in normal tissues, will produce typical shock when injected into animals. Cannon's (3) explanation of "traumatic toxemia" rested largely on this demonstration and was widely accepted as the solution of the problem. However, neither Cannon nor others explained satisfactorily the decreased blood volume characteristic of shock. Later it was shown that the amount of histamine necessary to cause shock in unanesthetized animals could not be derived from a limited area of damaged tissue. The explanation was questioned, since it failed to show the location of the "lost blood" and failed to demonstrate adequately an intoxicating substance originating in injured tissue.

In efforts to account for the decreased volume of blood some investigators resorted to the archaic dictum "shock is hemorrhage and hemorrhage is shock." Apparently the fact was overlooked that simple hemorrhage never causes hemoconcentration, but on the contrary causes dilution of blood.

Many ingenious experiments were devised in attempts to prove that all the manifestations of shock are due to local loss of blood and/or fluid at the site of the trauma. The experimentors offered no explanation for the frequent occurrence of shock, and for its experimental production, under conditions in which no local loss of blood or fluid had occurred. They seemed not to sense the significance of the visceral congestive edematous and ecchymotic features regularly present in shock. Such changes are not produced by local loss of fluid, nor by hemorrhage. The interpretations drawn from such experiments have not clarified the problem.

Shock has been regarded as purely a physiologic phenomenon with which surgeons were most concerned. For that reason it has been investigated chiefly by physiologists and surgeons. Hitherto pathologists have shown little interest in the condition. It has become apparently recently that a combined physiologic and pathologic study may contribute valuable information.

The method commonly used in studies on shock, is to narcotize an animal deeply with barbital or a similar drug. An arterial canula is inserted, and the blood pressure and pulse rate are recorded kymographically through a mercury manometer. Shock is then induced by extensive trauma to the muscles, by prolonged manipulation of the intestines or by some other form of tissue abuse. This method is open to serious objections. Variations in blood pressure and pulse rate are not accurate criteria of shock, since they often result from other conditions. The deep narcosis used often causes low blood pressure and other shock-like manifestations. Large amounts of blood are lost incident to the trauma. It is not possible to study minor degrees of shock nor to make prolonged observations, since it is impossible to keep the animal in a condition suitable for extended periods of study. The recorded phenomena may be due to the narcotic, to the trauma, to the associated hemorrhage, or in part to each. This combination of indeterminate factors has led to undependable conclusions.

Methods were devised to eliminate these objectionable features. Variation in concentration of the blood was used as a criterion, since it is well known that shock is accompanied regularly by hemo-concentration. Shock was induced without trauma by introducing muscle substance intraperitoneally, by injections of extracts of tissues, of bile, and by other means. These methods eliminate deep narcosis and hemorrhage as factors. They furnish an added feature of great value: varying degrees of shock can be produced and observations can be made on its later stages and sequellæ, uncomplicated by other factors. Observations were not limited to physiologic phenomena but included morphologic features. Distinctive changes occur regularly, and are of etiologic significance in shock as in other conditions of disease.

A quantity of muscle was excised aseptically from a freshly killed normal dog. This was finely ground in a meat chopper, and suspended in physiologic saline solution. Varying quantities of this preparation were introduced into the peritoneal cavities of normal dogs under light ether anesthesia. Records were made of the pulse rate, respiration, temperature and of the hemoglobin and red cell count three times each day before and following this procedure.

The following is a representative experiment. Under surgical asepsis, a quantity of muscle was implanted as described. The dog recovered well from the operation. He was active and even playful. Presently he refused all food, but drank water freely. He appeared acutely ill, refused to move about and shivered frequently. He vomited and had frequent bowel movements. These discharges contained blood-tinged mucus. The extremities became cold, the respirations became slow and deep and the pulse became very rapid and weak. He died ten and one-half hours following the operation. Changes in the concentration of the blood were as shown in the following table.

After death the peritoneal and pleural cavities contained thin, blood-tinged fluid. The peritoneum was intensely congested and all the minute vessels were markedly distended.

Hour	Specific Gravity	Hemoglobin Percentage	Red Cells
Average normal.......	1.059	98	5,820,000
6:30 a.m.........	1.060	101	5,110,000
7:00 a.m.........	Muscle substance into peritoneum		
10:30 a.m.........	1.065	94	4,860,000
1:30 p.m........	1.065	104	5,694,000
3:20 p.m........	1.067	108	5,695,000
4:50 p.m...... ..	1.075	120	6,400,000
5:15 p.m.........	1.075	130+	7,450,000 Death

The bowels contained bloody mucus, and the lining was swollen, edematous, and resembled purple velvet. Congestion was especially marked in the lungs (Fig. 1), liver and kidneys. Areas of capillary hemorrhage were present in the lungs and in the mucous and serous surfaces.

Microscopic examination showed acute edema and numerous hemorrhages associated with marked congestion of the capillaries and venules in each of the organs mentioned.

The implantation of smaller amounts of muscle substance produced exactly similar results except that death occurred at longer intervals. The same visible congestive changes were seen in the viscera. Marked pulmonary edema was a prominent feature (Fig. 3). The edema fluid had a high protein content, and its specific gravity closely approximated that of the blood plasma. This indicated that it resulted directly from increased capillary permeability. When a dosage of 3.0 gm. of muscle per kg. of body weight was implanted, death occurred on the fourth day following the operation. When smaller doses were used the dogs became acutely ill for several days and showed hemo-concentration of only 20 to 30 per cent. These dogs recovered.

In other experiments finely chopped muscle was suspended in physiologic saline solution and incubated for 24 to 48 hours at body temperature. This afforded opportunity for enzymatic autolysis of cellular substance. The fluid was then separated, sterilized by filtration, and its pH was adjusted to 7.4. The intravenous or intraperitoneal injection of such extracts produced immediate illness, hemo-concentration and

other evidences of circulatory disturbance. In one instance the intravenous injection of 20 cc. of extract caused the blood pressure to fall 100 mm. immediately (Fig. 2). The same congestive and edematous changes as described above were present in the viscera at postmortem examination following intravenous and intraperitoneal injections of muscle extracts.

In another group of dogs experimental obstruction of the bowel produced death by shock having the characteristic features of intestinal obstruction occurring in man. Hemo-concentration occurred early and the same congestive and edematous features as described were present regularly at postmortem.

In several experiments when hemo-concentration of 30 to 40 per cent indicated that an advanced degree of shock had developed, an intravenous injection of sterile neutral solution of trypan blue was made. This is a colloidal dye which is retained in the circulation under normal conditions, but which passes out rapidly into the tissues if the permeability of the capillary walls has been increased. When the animals died or were killed 2 or 3 hours following the injection of trypan blue, there was marked blueing of the mucous and serous surfaces and of the substance of the kidneys and other tissues. The edema fluid present in the serous cavities was distinctly blue. These experiments furnished visible evidence that in shock the permeability of the capillaries is markedly increased.

The capillary walls are sensitive to lack of oxygen and to other agents, and are delicately susceptible to toxic injury. When injured the capillaries not only dilate but their walls become abnormally permeable to the plasma fluid and allow it to leak out into the tissue spaces. About 30 years ago Heubner (4) found that the intravenous injection of certain poisons caused a rapid decline in blood pressure followed by circulatory failure and death in a few minutes. Widespread dilatation of the capillaries and venules in all the viscera was the outstanding postmortem feature in these experiments. The animals had bled to death into their own capillaries as he expressed it. His postmortem descriptions of the viscera

would apply without modification to the postmortem findings in shock.

Many substances affect the capillaries in a similar fashion. These include organic and inorganic poisons, drugs, histamine, products of protein cleavage, bacterial toxins and others. Landis (5) found that dilute solutions of mercuric chloride, veronal, alcohol and other toxic agents when injected into the blood increased the capillary permeability seven fold. Temporary lack of oxygen had a similar effect. Investigations (see Landis for review) on capillary phenomena indicate that any agent or condition causing injury to capillaries increased the permeability of their walls.

The following sequence of events results from the introduction into the circulation of some substance causing capillary injury. The capillaries, in areas such as the lungs, the gastro-intestinal mucosa and the parenchymatous organs become atonic and dilated. They become engorged with closely packed corpuscles, and a condition of stasis develops. This withdraws a large volume of blood from circulation as effectively as if by hemorrhage. The walls of the capillaries and venules become permeable to the plasma and allow it to escape. This causes edema of the tissues, lowers the blood volume, and leaves the blood relatively dehydrated. In such a case the corpuscular content of the blood may be from 40 per cent to 80 per cent higher than normal. This condition is referred to as hemo-concentration. The heart beats rapidly but ineffectively, and is unable to maintain normal arterial pressure because an insufficient volume of blood is returned to it from the tissues.

It was suggested by Dale (6) and his associates that traumatic shock was due to the absorption of histamine from areas of injured tissue, and that this affected the circulation in the manner described. In later experiments they found (Thorpe (7)) that 35 kg. of muscle would yield not more than 140 mg. of histamine. The minimal fatal dose of histamine phosphate given intravenously to dogs (Sollman (8)) is about 30 mg. per kg. of body weight. The amount derived from

35 kg. of muscle would not be fatal to a dog of average size. In several of our experiments 20 gm. of muscle, implanted intraperitoneally, caused fatal shock in dogs weighing 6 to 7 kg. The amount of histamine present in 20 gm. of muscle could not have produced this effect. Vaughan (9) has shown that products of protein cleavage, produced by chemical or enzymatic action, are highly toxic. These produced death by circulatory failure when injected into animals. These experiments were done (1906–1912) when little was known regarding shock. No records of blood pressure nor of blood counts were made, but the symptoms and postmortem findings described indicate that the animals died of shock. It seems probable that products of protein cleavage resulting from autolysis of injured tissues, are injurious to capillary endothelium, and that shock, following extensive injury or following the implantation of muscle substance, is due to the effects of these products.

Physicians have recognized that circulatory failure of the shock type occurs in conditions other than extensive trauma or surgery (Atchley (10), Eppinger (11), Warfield (12) and others). It is seen regularly following extensive burns, poisoning with certain drugs, intestinal obstruction, rupture of a viscus and in other abdominal emergencies. It also occurs in severe toxemias, as eclampsia, toxic jaundice, diabetes, and following infections of unusual severity. Our studies have included clinical and postmortem observations on numerous cases representing each of these conditions (13). Characteristic clinical manifestations of shock, including hemo-concentration, preceded death, and the postmortem findings were those typical and distinctive of shock.

We have produced experimental shock in dogs by methods paralleling closely the clinical conditions just mentioned (14). These methods have included superficial burns, experimental intestinal obstruction, injection of extracts of bowel mucosa and of other tissues, prolonged narcosis with sodium phenobarbital, injections of bile and of bile salts, of histamine, of bacteria and of the products of bacterial metabolism. In each instance these have produced the characteristic shock syn-

drome in the animals. Marked hemo-concentration and circulatory failure preceded death. In each instance the pathologic features distinctive of shock were present in the viscera.

Varying degrees of shock were produced. Minor degrees of shock were followed by recovery. The most severe degrees caused death in a few hours; lesser degrees led to death after intervals of days or of weeks. Pulmonary edema developed regularly in these cases of delayed death. The edema was a type which occurs frequently in man but which seldom has been reproduced experimentally. In these cases of experimental shock with delayed death a type of terminal pneumonia developed regularly in the edematous lungs (Fig. 4). The clinical occurrence and postmortem features of this type of pneumonia have been reported elsewhere (15). The production of sublethal shock in dogs furnished opportunity to study this type of pneumonia experimentally and confirmed the previous observations.

Summary

New methods for investigating shock have been developed. These obviate certain defects inherent in methods previously used, and provide new means for its recognition. Hemo-concentration indicates the presence of shock during life, and distinctive pathologic features indicate its presence postmortem. These are directly related to its mechanism of origin.

These features include marked engorgment of the capillaries and venules in mucous and serous surfaces, in the lungs, liver and kidneys; marked edema of lungs and mucosae, and effusions of fluid into serous cavities.

Shock may be produced by various intoxicating agents. These include substances derived from injured tissues as muscle substance, burns, and intestinal obstruction, the injection of tissue extracts, histamine, bile, poisonous drugs, or of bacteria or bacterial products. These findings corroborate the conception of "traumatic toxemia" advanced by earlier investigators.

When affected by various toxic agents the capillaries and

venules: (1) become atonic and dilated which increases the volume-capacity of the vascular system. (2) The capillary walls become abnormally permeable and allow the leakage of plasma from the blood into the tissue spaces. Such leakage produces edema, reduces the blood volume, and leaves the blood abnormally concentrated.

Pulmonary edema, of a type which occurs frequently in man, has been reproduced experimentally. It occurred regularly when death by shock was delayed 24 hours or longer.

Edema of the lungs predisposes to infection. A common form of terminal pneumonia developed regularly when a condition of moderate shock was maintained for several days. This confirmed previous observations on terminal pneumonia in man following sublethal shock.

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FIG. 1. Photograph of lung showing acute diffuse congestion and edema. Death of this dog occurred 36 hours following implantation of muscle substance in the peritoneal cavity. The microscopic features of this lung are shown in Fig. 3A.

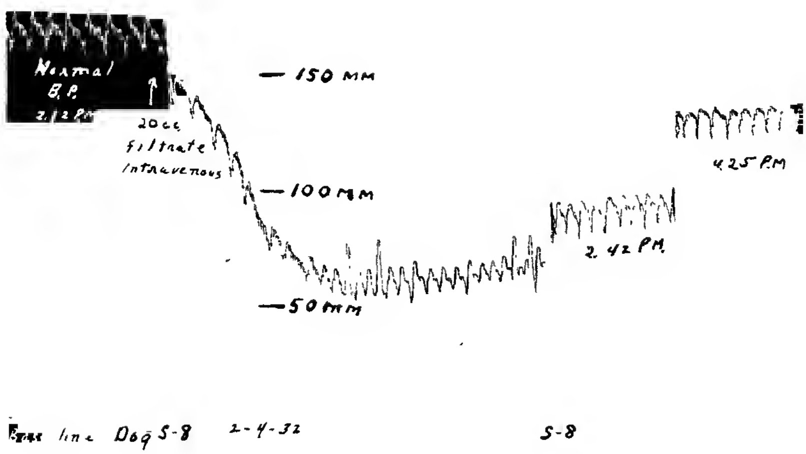
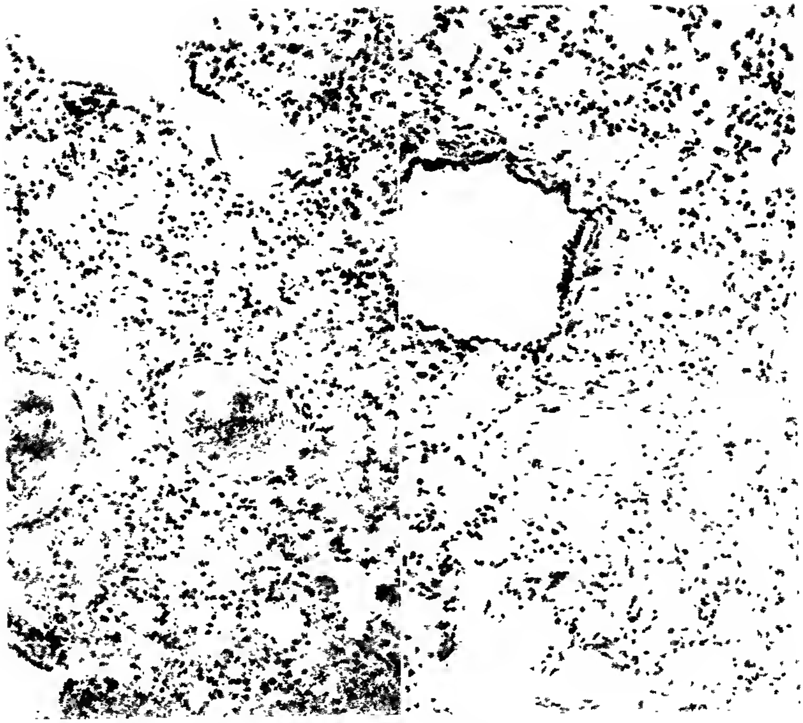


FIG. 2. Kymographic record of blood pressure following a single injection, 20 cc., of sterile neutral extract of muscle. Recovery followed this injection. Repeated injections produced fatal shock.



A *B*

Fig. 3. *A.* Microphotograph of lung following fatal shock from muscle implanted intraperitoneally. Marked congestion and edema are shown. *B.* Microphotograph of lung following repeated intravenous injections of sterile diluted dog bile. Marked edema is shown, and there is a slight leukocytic infiltration suggesting incipient pneumonia. Compare with Fig. 4 in which an early stage of pneumonia is present.

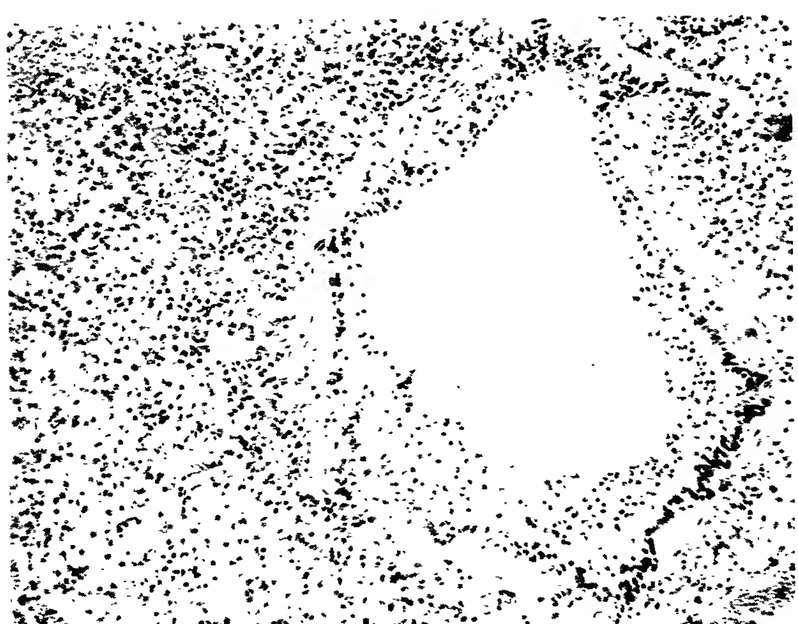


Fig. 4. Deep narcosis with sodium phenobarbital given by mouth resulted in death by circulatory failure in 4 days. The distinctive features of shock were present postmortem. Microphotograph of lung shows early pneumonia and bronchitis in addition to congestion and edema.

HEAT AND MOISTURE AS FACTORS IN THE INCREASED MUTATION RATE FROM DATURA SEEDS

J. L. CARTLEDGE,[1] L. V. BARTON, AND A. F. BLAKESLEE [2]

ABSTRACT

Seeds of the standard line of *Datura* were subjected to treatments with various environmental factors, particularly with heat and controlled moisture content, in investigation of the relation of these factors to the mutation rate. Increased rates of pollen abortion mutations had been found from seeds stored up to ten years in the laboratory, but had not been found in seeds buried 22 years in the soil. If their moisture content is low, many kinds of seeds will endure temperatures above 100° C. for an hour or more, but such treatments have not, apparently, been related to mutation rates. *Datura* seeds, while being held at controlled moisture contents from 2 per cent to 15 per cent, were treated at temperatures from 45° to 80° C. for times ranging from 2 hours to 5 days. The largest numbers were treated at 5 per cent moisture and 75° or 80° C. for 2 to 48 hours. All treatments were given at the Boyce Thompson Institute.

The most severe treatments killed the seeds, especially when these were high in moisture content, but moderate treatments increased the seedling yield over that of the controls. Good germination was obtained from treatments of seeds with 5 per cent moisture for 24 hours at 80° C., and for 36 hours at 75° C. The interval between planting and appearance of the seedlings was increased by increases in temperature, by increases in moisture content, and especially by increases in duration of treatment. Seeds with moderate and severe heat treatments produced high percentages of plants with abnormal growth, as reflected in their types of branching.

The plants were tested for pollen abortion mutations by microscopic examinations of pollen samples. Mutations of the pollen-abortion gene type were found in 56 plants, while pollen abortion of the type caused by chromosomal mutations occurred in 37 plants. Although a total of 93 pollen-abortion mutations were thus found in the 8741 plants tested, none of these were found in the 920 control plants. Most of the mutations involved a sector of half or of less than half of the plant. Within the exposure times used there was no significant increase of mutations at temperatures lower than 70° C. The highest mutation rates found were about 5 per cent, obtained from seeds with 5 per cent moisture content heated at 75° and 80° C. Higher rates were obtained from aged seeds. In general the mutation rate increased with increased temperature, with increased moisture content, and with increased duration of treatment.

IN AN earlier publication (4) [3] it has been shown that seeds of *Datura* which were aged by storage in the laboratory for periods up to ten years have increased mutation rates for pollen-abortion mutations, and that these mutations are in-

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[2] Aided by research grant from the Committee on Radiation, National Research Council.

[3] See "Literature Cited."

herited. This work followed the discovery by Navashin (14) that in root tips of plants grown from aged seeds of *Crepis* chromosomal abnormalities were produced in large numbers. Shortly later Peto (17) also found large numbers of chromosomal mutations in root tips of maize from aged seeds. The work on *Datura* has been extended by showing that high rates of visible mutations are also induced (2, 3) and that the aging of pollen grains for periods up to 13 days is even more effective for increasing the pollen-abortion mutations than aging seeds (6). Stubbe (19) reports that aging seeds of *Antirrhinum* greatly increases the rate of visible mutations.

These results raise the question of the causes of the increased mutation rates following aging. That the increases are not due to age alone is indicated by the results of study of *Datura* plants grown from seeds that were aged for 22 years in the soil (5). These plants showed rates of pollen-abortion mutation but slightly higher than the rates found for their controls. Investigation of the effects on the mutation rate of varying the environmental factors to which the seeds might be subjected was thus suggested. Peto (17) has shown for barley and Navashin and Shkvarnikov (16) for *Crepis* that heating seeds is more effective than aging for the production of chromosomal mutations in the root tips. Although many other accounts of experiments on heating seeds may be found in the literature they seem to be connected with the control of fungal or bacterial parasites, or with the effects of the treatment upon the germinability of the seeds, or, in a few cases, with the abnormal growth of the seedlings from heated seeds.

When the moisture content is very low, seeds of many sorts will endure surprisingly high temperatures. Harrington and Crocker (11) germinated seeds of Johnson grass that were heated for six hours at 100° C. with moisture content of from 2.0 per cent to 0.1 per cent, but the seedlings produced were less vigorous than their controls. Waggoner (20) reported that 14 per cent of seeds of the Icicle radish were viable after heating for 30 minutes at 123° C. with 0.4 per cent moisture

content, but that all died at 100° C. with 4 per cent moisture, and at 65° C. with 40 per cent moisture. By preheating for one day at 65° to 75° C., and one day at 90° C., Dixon (8) germinated seeds of a number of plant species after heating them at temperatures ranging from 100° to 114° C. Atanasoff and Johnson (1) heated well-dried seeds of wheat, barley, oats and rye at 100° C. for 15 and 30 hours, and of wheat and barley at from 100° to 110° C. for 45 hours, and got good germination, except for the rye which germinated poorly. Earlier literature on heating seeds is reviewed in the papers of Waggoner (20) and of Atanasoff and Johnson (1).

Waggoner, and other investigators, have noted that heating of seeds may cause delay in their germination. Crocker and Groves (7) found that wheat seeds delayed the beginning of their germination from 4 to 14 days, depending upon the length of heating. Jozefowicz (12) found that increasingly severe heat treatments of tomato seeds caused progressive delay in their germination, which occurred from 10 to 18 days after planting. Seedlings grown from seeds that have been subjected to severe heat treatments may show abnormalities of growth and form. Jozefowicz (13) obtained from 50 per cent to 100 per cent of abnormal tomato seedlings from seeds heated at 90° to 100° C. for one hour, unless the seeds were carefully pre-dried. Gain (9) grew sunflower plants from desiccated embryos which had endured a series of successively more severe heat treatments, ending with temperatures raised from 125° to 155° C. during about 30 minutes time. The plants grown from embryos so treated were very abnormal in form and growth, and although some of them produced flowers, none was able to form seeds (10).

The seeds used in the experiments reported in the present paper were bred by self-pollinating a few of the standard Line 1 *Datura* plants, except for seeds of series IX which were from the plants grown from the 22-year-old seeds mentioned above. The standard line has been inbred since 1916, and has been passed through a haploid. It has been extensively bred, and has furnished most of the material for the genetical

and cytological studies on the genus. All of the treatments of the seeds were done at the Boyce Thompson Institute, but the seeds were germinated in soil in the greenhouse at the Department of Genetics of the Carnegie Institution of Washington, where the plants were grown. When the moisture content of each series of seeds was determined from a sample, the remaining seeds were placed in sealed vials so that their moisture content would remain constant until adjustment was begun. Moisture content was increased or decreased by storing in a desiccator over water or over CaO until the seeds had absorbed or lost the required amount. This point was determined by bringing them to the desired weight, calculated from the previously determined initial moisture content. The seeds were then placed in vials just large enough to hold them, and sealed with hard De Khotinsky cement. These vials were placed in pre-heated, cork-stoppered bottles, and then subjected to the required temperatures in a glycerine bath within the oven. Seeds for series VIII were placed in 500 cc. flasks. The gases used were passed through these for about a minute, then the flasks were sealed and placed in the oven. There was, no doubt, a decrease in the moisture content of the seeds while being heated in these larger containers.

The method of testing plants for pollen-abortion mutations was by the microscopic examination of two pollen samples, from flowers from each of the two main branches of each plant. By this means, as has previously been reported (4), we can distinguish in the majority of cases such chromosomal mutations as are associated with pollen abortion (segmental interchanges, simple translocations, and breaks) from those gene mutations which cause abortion of the 50 per cent of pollen grains which receive the mutant gene, since in most cases the gene mutations cause abortion at a later stage of pollen development. Mutations of these two sorts together furnish an index to the mutation rate which is somewhat more delicate than the index obtained from the incidence of visible recessive gene mutations. In *Datura*, at least, fewer recessive gene mutations than pollen-abortion mutations were found in both

radiation and aged seed experiments. The pollen-abortion index is also more convenient and efficient, since the plants grown directly from the treated seeds are used. This saves the breeding of another generation of plants in sufficient numbers for the detection of visible recessive mutations from each treated parent plant.

Preliminary experiments were made in the spring and summer of 1934. Some of these were germination tests only, but from others, tests for pollen mutations were made on 204 plants from heat-treated seeds and 38 control plants. No mutations were found. However, later experiments showed that only 34 of the tested plants had been given sufficient heat to permit expectation of increase in mutation rate. Later in the summer (1934) a more extensive series of treated seeds was cultured. The plants were grown under adverse seasonal and field conditions, and many were so heavily infected with a mosaic disease that they did not provide material for pollen tests. The tests that were made, however, showed that sharp increase in mutation rates occurred when seeds were heated at 5 per cent moisture and 80° C. for 12 and 16 hours. Seedling production, as measured by counting the total number of seedlings that appeared above the surface of the soil in the seed pans, was sharply reduced by treatments at about 5 per cent moisture and 80° C. for 16 and 20 hours, and at about 10 per cent moisture and 65° C. for 8 hours. No seedlings were obtained from seeds given longer treatments at these levels. Less severe treatments, on the other hand, regularly yielded greater seedling production than did the unheated controls. There was also a delay in the appearance of the seedlings, apparently correlated with the severity of the heat treatment, and in some cases abnormal plants were produced. A summary of the data on mutations from this preliminary series is given in Table 1.

Four series of seeds, which will be referred to as series I to IV, were treated in the winter of 1934–5, and the plants from them were grown in the greenhouse. These four series were studied in respect to seedling production, delay in the

TABLE 1.

Treatments			Plants Tested	Mutations	Per Cent Mutations
Temperature	Moisture	Hours			
45° C.	2%	8–120	423	0	0.0
65° C.	2%	8–120	420	2	0.5
80° C.	2%	8–48	226	2	0.9
45° C.	5%	8–120	492	1	0.2
65° C.	5%	8–48	288	1	0.3
80° C.	5%	8–20	91	7	7.7
45° C.	10%	8–120	439	2	0.5
65° C.	10%	8	1	0	0.0
Total treated			2380	15	0.63
Controls			121	0	0.0

appearance of the seedlings, and gross abnormalities of growth and form, as well as for the mutation rates. The experiments projected were: (Series I), seeds with 5 per cent moisture content, heated at 80° C. for durations varied from 2 to 24 hours by two hour intervals; (Series II), seeds with moisture content varied at 1, 2, 5, 7.5 and 10 per cent, heated at 80° C. for 12 hours; (Series III), seeds heated at temperatures varied at 2.5° steps from 65° to 80° C. with moisture content and duration constant at 5 per cent and 12 hours; (Series IV), seeds with 5 per cent moisture content heated at 75° C. for durations varied from 8 to 60 hours by four hour intervals. The actual percentages of moisture obtained for the different lots of seeds varied considerably from the desired figures. In series I the actual moistures were below, and in the other series above the amounts planned. The oven temperatures also varied around the desired temperatures, although the temperatures of the seeds probably did not vary quite so much. In series I the oven temperatures ranged from 78° to 81° C., with five of the seven readings made at two hour intervals more than one-half of one degree below or above 80° C. For series II the oven temperatures went from one-half to one degree higher than desired, and in one case (72.5 desired), two degrees higher. Variation from only 79.5° to 80° C. was noted for series III, but in series IV the range was from 74.5° to 77° C.

The number of seeds used for each treatment varied from 145 to 153, with 150 the most common number. Data on number of seeds, treatment, seedling production and delay in appearance of the seedlings are shown in table 2, together with the percentage of pollen mutations. Two measures for the delay in the appearance of the seedlings are there given: (1) the number of days elapsed between the day of planting and the day of the appearance of the first seedling, and (2) the number of days elapsed between planting and the appearance of 50 per cent of the total number of seedlings that actually appeared. Counts of seedlings were made at two day intervals. When more than 90 per cent of the expected seedlings had appeared after 36 to 60 days, the seed pans were discarded. The other pans were watched until from 112 to 136 days after planting. One pan of controls, with 150 seeds, was discarded by error after 84 seedlings had appeared in 54 days. It is not likely that many more seedlings would have come up if the pan had been kept, since only 28 of the 384 seedlings produced by the other controls appeared after the 54th day.

In general the seedling production from heat-treated seeds was greater than that from the controls. In the most severe treatments the numbers of seedlings were reduced (341532, 341533, Table 2) or there was no germination (Series III: 7.5

TABLE 2

Series I. Seeds Heated at 80° C.

Pedigree Number	Moisture Content	Hours Heated	No. of Seeds	Per Cent Seedling Production	1st Seedling, Days	50 Per Cent Seedlings, Days	Mutations, Percentage
341500	4.54%	2	149	71.8	11	11	0.0
341501	4.47%	4	146	94.5	13	17	0.8
341502	4.47%	6	151	94.0	13	17	1.4
341503	4.47%	8	148	94.6	17	19	0.8
341504	4.53%	10	153	86.9	19	23	0.0
341505	4.53%	12	151	94.7	19	21	3.2
341506	3.71%	14	148	92.6	25	31	4.5
341507	3.71%	16	150	96.7	25	35	5.3
341508	4.61%	18	149	99.3	29	35	4.6
341509	4.61%	20	153	81.0	33	41	3.3
341510	4.22%	22	150	92.7	17	21	1.5
341511	4.22%	24	151	93.4	29	37	2.8
Controls			150	67.3	9	13	0.0

and 10 per cent moisture; series IV: 48, 52, 56, and 60 hours). On the other hand the least severe treatments did not have the stimulating effect on seedling production (341500,

TABLE 2—(Continued)

Series II. Seeds Heated for 12 Hours

Pedigree Number	Moisture Content	Hours Heated	No of Seeds	Per Cent Seedling Production	1st Seedling, Days	50 Per Cent Seedlings, Days	Mutations, Percentage
		Temperatures					
341512	5.38%	65.5–66	150	16.7	14	16	0.0
341513	5.59%	67.5–68	148	91.2	10	12	0.0
341514	5.59%	70 –70.5	149	86.6	10	10	0.0
341515	5.59%	72.5–74.5	150	93.0	22	24	2.0
341516	5.63%	75 –76	150	100.0	22	24	1.6
341517	5.63%	77.5–78	150	98.7	22	26	4.9
341518	5.63%	78	150	13.3	42	56	—
Controls			145	47.6	13	16	0.0

Series III. Seeds Heated at 80° C. for 12 Hours

Pedigree Number	Moisture Content	Hours Heated	No of Seeds	Per Cent Seedling Production	1st Seedling, Days	50 Per Cent Seedlings, Days	Mutations, Percentage
341519	2.69%		150	74.0	7	7	0.0
341520	2.70%		145	81.4	7	11	0.0
341521	5.13%		150	92.0	23	27	1.7
Controls	2.70%		37	64.9	7	17	0.0
Controls	5.13%		38	81.6	7	17	0.0
Controls	7.87%		150	56.0*	9	23	0.0
Controls	9.81%		150	37.3	7	25	0.0

Series IV. Seeds Heated at 75° C.

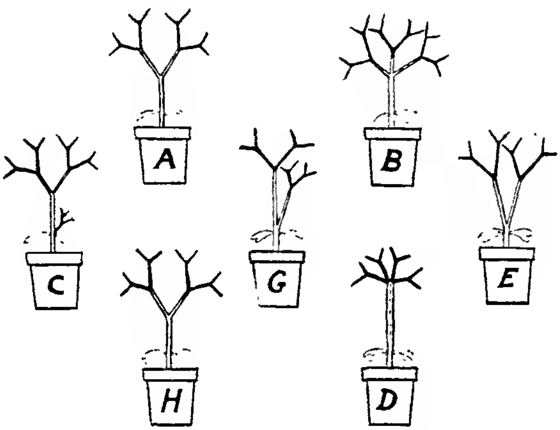
Pedigree Number	Moisture Content	Hours heated	No of Seeds	Per Cent Seedling Production	1st Seedling, Days	50 Per Cent Seedlings, Days	Mutations, Percentage
341524	5.68%	8	150	90.7	16	20	0.9
341525	5.68%	12	150	93.3	18	22	0.8
341526	5.68%	16	150	100.0	22	28	0.8
341527	5.68%	20	150	99.3	28	30	1.8
341528	5.46%	24	149	98.0	28	30	1.5
341529	5.46%	28	150	94.7	34	42	4.7
341530	5.01%	32	150	81.3	34	40	0.0
341531	5.01%	36	150	89.3	36	44	2.0
341532	5.70%	40	149	50.3	38	38	3.3
341533	5.70%	44	149	2.7	78	78	—
Controls			301	32.9	10	12	0.0

* Records incomplete.

341512, Table 2). Between these extremes the effect seems fairly uniform. Thus, in series I, about the same percentages of seedlings were obtained at 6, 12, and 24 hours treatment (Table 2). Heat treatments caused delay in the appearance of the seedlings, and the amount of this delay was very clearly dependent upon the severity of the treatment, either on the duration of treatment (Series I and IV) or on the temperature (Series II) or on the moisture content (Series III). One exception to the progressive delay in appearance of seedlings with progressively severe treatments must be noted. In series I the results from pedigrees 341510 and 341511, both from the same parent seed capsule, are exceptional in respect to both delay and mutation. They behaved as would have been expected if the seeds were heated for about 10 and 18 hours instead of 22 and 24 hours respectively. While the differences in the mutation rates may be chance ones, the pronounced differences from the expected delay in the time of appearance of seedlings are difficult to explain. The behavior of the unheated control seeds from this same capsule affords no explanation of the exceptional behavior of the heated seeds, since these controls behaved almost exactly as the average for controls of series I (Table 2). On the whole the delay in the appearance of seedlings from these heat-treated *Datura* seeds seems to be more extreme and more nearly parallel to the degree of severity of the treatments than is the case for other materials of which we have seen reports in the literature. This suggests that *Datura* may be excellent material for the study of the physiology of the delay in growth following heat treatments of seeds.

Many, and in some of the treatments, most, of the heated seeds produced plants which were abnormal in form. While a few of these plants showed extreme abnormalities of various types, most of them could be classified under a few rather distinct types on the basis of shape of the cotyledons and type of branching above the cotyledonary node. The normal branching type in *Datura* has a series of dichotomous forks, beginning some distance above the cotyledons. The first and

second dichotomies from the main stem usually show paired branches of about equal size. but beyond these the paired branches are usually unequal. Late in the development of the plant smaller lateral branches may appear below the first main fork. A diagram of the normal type of branching system is shown in Text-Fig. 1*A*. The other types under which the



TEXT-FIG. 1. Diagrams of the classified types of abnormal branching from heated *Datura* seeds. (*A* represents the normal type.)

abnormally branching plants were classified are represented by the diagrams B to H in the same figure. Type "B" is tri-forked at the first or main forking. The third branch may be equal in size to the other two, but frequently it is smaller. There were 1.1 per cent tri-forked plants among the controls, and there is generally a small percentage of plants of this type among otherwise normal plants. The B-type plants occurred in slightly higher percentages among the plants from heat-treated seeds, and especially from seeds that received relatively light heat treatments (Table 3). Seven, or 2 per cent of the control plants were classified as otherwise abnormal, but five of these were of the F-type. This last is the designation employed for the extremely abnormal appearing plants that are "blind" due to the loss or injury of the growth point of the epicotyl. Since F-type plants are very various in appearance there is no diagram for this type in Fig. 1. The

TABLE 3

HEAT TREATMENT OF SEEDS

PLANTS OF ABNORMAL BRANCHING TYPES WITH THEIR PERCENTAGES

Pedigree Number	Treatment	Plants	A	B	C	D	E	F	G	H	Total B–H
341500	5% 80° 2 hrs.	91	91	0	0	0	0	0	0	0	0
			100.0	—	—	—	—	—	—	—	—
341501	5% 80° 4 hrs.	124	114	6	2	0	1	1	0	0	10
			91.9	4.8	1.6	—	0.8	0.8	—	—	8.1
341502	5% 80° 6 hrs.	138	130	4	0	2	1	1	0	0	8
			94.2	2.9	—	1.4	0.7	0.7	—	—	5.8
341503	5% 80° 8 hrs.	120	86	6	1	13	12	0	1	1	34
			71.7	5.0	0.8	10.8	10.0	—	0.8	0.8	28.3
341504	5% 80° 10 hrs.	127	66	1	5	19	18	4	11	3	61
			52.0	0.8	3.9	15.0	14.2	3.2	8.7	2.4	48.0
341505	5% 80° 12 hrs.	125	21	1	9	13	63	2	14	2	104
			16.8	0.8	7.2	10.4	50.4	1.6	11.2	1.6	83.2
341506	5% 80° 14 hrs.	126	80	3	21	4	11	2	2	3	46
			63.5	2.4	16.7	3.2	8.7	1.6	1.6	2.4	36.5
341507	5% 80° 16 hrs.	125	66	3	20	7	19	4	5	1	59
			52.8	2.4	16.0	5.6	15.2	3.2	4.0	0.8	47.2
341508	5% 80° 18 hrs.	139	101	0	14	9	7	3	3	2	38
			72.7	—	10.1	6.5	5.0	2.2	2.2	1.4	27.3
341509	5% 80° 20 hrs.	105	61	3	10	17	7	1	3	3	44
			58.1	2.9	9.5	16.2	6.7	1.0	2.9	2.9	41.9
341510	5% 80° 22 hrs.	132	60	0	7	8	45	4	4	4	72
			45.5	—	5.3	6.1	34.1	3.0	3.0	3.0	54.5
341511	5% 80° 24 hrs.	117	48	2	35	3	22	0	7	0	69
			41.0	1.7	29.9	2.6	18.8	—	6.0	—	59.0
341512	5% 65° 12 hrs.	23	23	0	0	0	0	0	0	0	0
			100.0	—	—	—	—	—	—	—	—
341513	5% 67.5° 12 hrs.	125	97	2	0	17	8	0	1	0	28
			77.6	1.6	—	13.6	6.4	—	0.8	—	22.4
341514	5% 70° 12 hrs.	121	119	2	0	0	0	0	0	0	2
			98.3	1.7	—	—	—	—	—	—	1.7
341515	5% 72.5° 12 hrs.	105	69	0	1	13	17	3	1	1	36
			65.7	—	1.0	12.4	16.2	2.9	1.0	1.0	34.3
341516	5% 75° 12 hrs.	137	56	1	12	12	39	5	9	3	81
			40.9	0.7	8.8	8.8	28.5	3.6	6.6	2.2	59.1
341517	5% 77.5° 12 hrs.	134	49	4	16	8	38	2	7	10	85
			36.6	3.0	11.9	6.0	28.4	1.5	5.2	7.5	63.4
341519	2% 80° 12 hrs.	99	98	0	0	0	1	0	0	0	1
			99.0	—	—	—	1.0	—	—	—	1.0
341520	2% 80° 12 hrs.	103	101	0	0	1	0	1	0	0	2
			98.0	—	—	1.0	—	1.0	—	—	2.0
341521	5% 80° 12 hrs.	121	52	3	12	3	47	0	2	2	69
			43.0	2.5	9.9	2.5	38.8	—	1.7	1.7	57.0
341524	5% 75° 8 hrs.	113	110	2	0	0	1	0	0	0	3
			97.3	1.8	—	—	0.9	—	—	—	2.7
341525	5% 75° 12 hrs.	133	123	5	3	0	0	2	0	0	10
			92.5	3.8	2.3	—	—	1.5	—	—	7.5

TABLE 3—*Continued*

Pedigree Number	Treatment			Plants	A	B	C	D	E	F	G	H	Total B–H
341526	5%	75°	16 hrs.	123	56	4	7	18	33	1	4	0	67
					45.5	3.3	5.7	14.6	26.8	0.8	3.3	—	54.5
341527	5%	75°	20 hrs.	119	44	2	4	14	43	1	11	0	75
					37.0	1.7	3.4	11.8	36.1	0.8	9.2	—	63.0
341528	5%	75°	24 hrs.	136	14	0	26	0	84	1	10	1	122
					10.3	—	19.1	—	61.8	0.7	7.4	0.7	89.7
341529	5%	75°	28 hrs.	127	69	0	23	5	19	0	8	3	58
					54.3	—	18.1	3.9	15.0	—	6.3	2.4	45.7
341530	5%	75°	32 hrs.	74	23	0	7	0	35	0	9	0	51
					31.1	—	9.5	—	47.3	—	12.2	—	68.9
341531	5%	75°	36 hrs.	109	43	0	10	1	31	1	23	0	66
					39.4	—	9.2	0.9	28.4	0.9	21.1	—	60.6
341532	5%	75°	40 hrs.	65	31	1	9	3	14	0	5	2	34
					47.7	1.5	13.8	4.6	21.5	—	7.7	3.1	52.3
	Controls			353	342	4	0	0	2	5	0	0	11
					96.9	1.1	—	—	0.6	1.4	—	—	3.1

percentage of F plants from heated seeds averages no higher than that from the controls, but, as shown in table 3, there are very considerable increases in the percentages of the types C, D, E, G, and H. Diagrams of these types are shown in the figure.

In type E there is abnormal forking of the main stem into two similar branches, at a point just above the cotyledons, and a second forking at about the place of the first fork in normal (A-type) plants. Type D differs from E in that the first fork is incomplete and the partly separated branches of the main stem are fused from the cotyledons up to the point where the first fork would normally occur. Here the second forks appear, as in the E-type, except that in D the branches from both of the second forks are crowded together because of the fusion of the main branches below. The other types differ from E by the decrease in the size of one of the two main branches by progressive steps to G, to C, and to H. These types are increasingly difficult to recognize and record, and many of the C- and H-types may have been overlooked, since C may appear like a normal plant with a small, low-placed, lateral branch; while H may seem quite normal—as

though one of the abnormal first branches had disappeared and the remaining one had simulated the main axis of the normal type. However, in these two types, as well as in D, E, and G, there is usually partial to nearly complete division or forking of one or of both of the cotyledons. Plants of the H-type were recorded by this characteristic of their cotyledons, but without doubt many records were lost before the necessity for this observation was apparent. Although the cotyledons are shed before the plant shows an extensive branch system, their forms, in positions as at earlier stages, are shown by dotted lines in the diagrams of Fig. 1.

Data on the distribution of these types, in relation to the heat treatment of the seeds, are given in table 3, where both numbers of plants and percentages are shown under the letter designations which may be referred to the diagrams in Fig. 1. The least severe treatments, in all four series, produced no effects on the branching of the plants, but nearly all of the other treatments induced abnormal branching in many of the plants grown from the treated seeds. In both of the longer series of related treatments, series I and series IV, the greatest proportions of abnormal plants occur at about the middle, rather than at the end of the series where, following the most severe treatments, the maximum effect might be expected. Thus, in series I, seeds heated for 12 hours gave 83.2 per cent abnormal plants, while those heated for longer times gave only from 27.3 per cent to 59.0 per cent abnormal types. Likewise in series IV the maximum effect (89.7 per cent abnormals) was obtained at 24 hours heating, and longer treatments gave from 45.7 per cent to 68 per cent. It is not at once apparent how this curious relationship between treatment and abnormalities may be brought about, such that higher proportions of abnormal plants appear from less severely treated seeds, and that continued heating of the seeds reduces the numbers of these types. The effects of differential germination or viability (Table 2) could account for but little of the differences found. In pedigree culture 341508 all except ten of the heated seeds are represented by recorded plants. If all ten

of these seeds should have produced abnormal plants there would still have been but 48 of these from 149 seeds with the 18 hour treatment, whereas there were 104 abnormals among 125 recorded plants from the 12 hour treatment in the same series. In all of the cases under consideration even when the total number of plants was low, there were larger numbers of normal plants recorded than in the pedigrees which showed the highest percentages of abnormals. Although the seeds for each series were taken from single parent plants, there seem to be very considerable differences between the lots of seeds from different seed capsules in respect to their response in producing abnormal plants after heat treatments. Such differences might be related to uncontrollable variations in the growth and ripening of the seed capsules. In series I (Table 3) the seeds for the 10 and 12, the 14 and 16, the 18 and 20, and the 22 and 24 hour treatments were in each case from the same capsule for the two treatments, and although there are large differences in the percentages of abnormal plants from each pair, the more severe treatment within each pair has resulted in the larger percentage of abnormal plants. On the other hand, in series IV, the seeds for the 24 and 28, and for 32 and 36 hour treatments are also, for each pair, from the same capsules, and here the reverse is true, the percentages of abnormal plants are lower from the more severe treatments, and markedly so in the case of the 24 and 28 hour ones. These last differences can scarcely be due to differences in the condition of the seeds; either they are real differences due to an apparently inexplicable reversing effect of continued heat-treatment, or they are apparent differences due to some error in the experimental procedure.

The seeds for the 24 and 28 hour treatments in series IV were alike, and were treated alike, except that one lot remained in the 75° oven four hours longer than the other. The same is true for the seeds given 32 and 36 hour treatments. The differences in the percentages of abnormal plants from these two pairs of treatments can be referred chiefly to differences in the E-type (Table 3). There are as high or higher

percentages of the C-, G-, and H-types, taken together, in the pedigrees which show lower total percentages of abnormals than in the other pedigree of each pair. In general the proportion of the C-, G-, and H-types combined tends to be greater from the more severe treatments. This may indicate that increased severity of treatment tends to increase the degree of injury or abnormality, so that more of these types are then recorded. But, if we are correct in supposing that the total repression of one of the main branches produces the H-type plants, then this most severe of the types of injuries is most likely to escape our observation, and these plants to be recorded as normal or A-type. We have no way of knowing how frequently this error may have occurred; it may have been so common an error as to account for the increased numbers of A records and the corresponding decrease of total abnormal ones from the pedigrees of plants with the more severe treatments. If this be the case, then the decrease in abnormal plants from treatments beyond those of moderate severity is apparent rather than real.

The primary purpose of these experiments was to test the effects of the treatments selected as possible factors in the increased mutation rates obtained from aged seeds. The percentages of plants with mutations in each of the pedigrees in series I to IV have been shown in table 2 for comparison with seedling production at each level of treatment. In table 4 the rates of mutation are shown by groups of three pedigrees each for series I, II and IV, together with the numbers and kinds of mutations for each group. In series III only two mutations, both of the chromosomal type, were found among the 115 plants from seeds treated at 5 per cent moisture. The 202 plants tested which were grown from seeds treated with about 2.5 per cent moisture showed no mutations. Series I, treated at 80° C. and 5 per cent moisture, shows increasing rates of mutation with increasing duration of treatment up to the 14–16 hour group (more specifically, to the 16 hour treatment (Table 2)) and some decrease in the rate at longer durations. This decrease at the end of the series

TABLE 4

Treatments, 5 Per Cent Moisture, 80° C., for	No of Plants Tested	Pollen Abortion Mutations				Differences	Diff./P.E.
		Chromosomal Types	Gene Types	Total	Percentage		
2, 4, 6 hrs. . .	352	0	3	3	0.9±0.34		
8, 10, 12 hrs . .	374	3	2	5	1.3±0.40	0.4±0.52	0.8
14, 16, 18 hrs. . .	356	7	10	17	4.8±0.76	3.5±0.86	4.1
20, 22, 24 hrs. . .	330	1	7	8	2.4±0.57	2.4±0.95	2.5
5% moisture, 12 hrs., at							
65–70° C.	268	0	0	0	———		
72.5–77.5° C. . .	346	3	7	10	2.9±0.61	———	—
5% moisture, 75° C., for							
8, 12, 16 hrs. . .	356	3	0	3	0.8±0.32		
20, 24, 28 hrs. . .	356	3	6	9	2.5±0.56	1.7±0.64	2.6
32, 36, 40 hrs. . .	228	2	2	4	1.8±0.59	0.7±0.81	0.9
Controls	335	0	0	0	0.0 —		

may not be significant (Table 4). The highest rate of mutation (Series I, Table 4) is about the equivalent of the rate found for four to five year old seeds (4) and is lower than the rates from seeds older than five years. Although the mutation rates for series IV, the seeds of which were treated at 5 per cent moisture and 75° C., are somewhat lower than for the 80° series (Table 4), the 28 hour treatment gave 4.7 per cent mutations (Table 2). Again in this series the most severe treatments gave lower rates of mutations, but these differences are less likely to be significant ones than those in the first series (Table 4). Comparison of controls, in which no mutations were found, with plants from treated seeds—as well as comparison of rates from the less and more severe treatments within a series—clearly shows that the treatments bring about higher rates of mutation. These increases in

mutation rates may be related either (*a*) to greater duration of treatment at a given temperature and moisture content of the seeds, or (*b*) to increased temperature at the same moisture and duration of treatment (Series II), or (*c*) to increased moisture content of the seeds when temperature and duration of treatment are constant (Series III, text above). The three factors, temperature, time, and moisture content, which have been shown to influence germination and the abnormal growth of seedlings (Table 3), can thus be shown to influence the rate of mutation. This fact seems to be of considerable importance for an understanding of the nature and cause of mutation.

During the summer of 1935, plants from treated seeds of series V to IX were grown and tested for pollen mutations. These tests were made to extend the duration of treatment at 5 per cent moisture and 80° C. (Series V); to test the effect of drying at high temperature (Series VI); to extend the range of moisture contents tested (Series VII); to test the effects of atmospheric gases (Series VIII); and to check the mutation rate for material of the Virginia race which was used in tests of 22-year old buried seeds (5) (Series IX). Again in this summer we failed to obtain records as complete as those for the greenhouse grown material, and again the seeds did not endure as severe heat treatments as those at which similar seeds were successfully treated a few months earlier. In the cases where germination was secured the seedling production was rather high, from 88 to 100 per cent for all except three pedigree cultures in series VII which gave 70 per cent, 63.3 per cent and 0.7 per cent (Table 5). However, no seedlings were obtained from treatments longer than 12 hours at 5 per cent moisture and 80° C. (Series V). Seedling production was zero at 7.5 per cent—75° C.—12 hours and 24 hours, but was 63.3 per cent at 18 hours (Table 5). No seedlings were obtained from 7.5 per cent—80° C. for 8, 12 and 16 hours, nor from 10 per cent—75° C. for 4, 8 or 12 hours, and 10 per cent—80° C. for 4 and 8 hours, nor at 15 per cent moisture and 75° or 80° C. for 2 and 4 hours each. The types of ab-

TABLE 5

Series; Pedigree Numbers	Seed Treatments			Seedlings Produced				Mutations			
	Moisture, Per Cent	Temp. ° C.	Hrs.	Per Cent	First, Days	50 Per Cent, Days	Plants Tested	Chromosomal	Gene Type	Total	Per Cent
Series V											
3403000	5.77	80	12	89.3	30	34	61	2	0	2	3.3
3403045.....	6.30	Control		90.0	8	10	96	0	0	0	0.0
Series VI											
3403005	Open	75	24	94.7	10	10	129	0	0	0	0.0
3403006. ...	Open	75	120	99.3	8	10	132	0	0	0	0.0
Series VII											
3403011.. ..	5.71	60	48	96.7	10	12	120	0	0	0	0.0
3403012.. ..	5.88	60	60	94.7	10	10	116	0	1	1	0.9
3403013......	5.76	60	72	96.0	10	10	109	0	0	0	0.0
3403014.. ..	5.52	75	24	95.3	34	38	62	2	5	7	11.3
3403015 . .	8.24	60	18	99.3	10	10	117	1	0	1	0.9
3403016.. ..	8.27	60	24	100.0*	10	10	137	0	0	0	0.0
3403017 . .	8.44	60	30	88.7	10	12	100	0	0	0	0.0
3403019 .	7.67	75	18	63.3	32	42	48	1	1	2	4.2
3403024.	10.91	60	4	92.7	8	10	97	0	0	0	0.0
3403025	10.91	60	8	92.0	8	10	96	0	0	0	0.0
3403026 . . .	11.74	60	12	70.0	10	10	50	0	0	0	0.0
3403033	17.31	60	2	89.3	8	10	67	0	0	0	0.0
3403034 ..	17.40	60	4	0.7	24	24	1	0	0	0	0.0
3403035 .	17.03	60	8	92.7	12	12	84	0	0	0	0.0
3403044 .. .	6.30	Control		93.2	8	10	74	0	0	0	0.0
3403032.. ..	11.48	Control		90.0	10	10	95	0	0	0	0.0
3403038...	17.15	Control		91.3	8	10	96	0	0	0	0.0
Series VIII											
3403041. ...	5.78	80 (O_2)	12	96.5	10	10	95	0	0	0	0.0
3403042 . .	5.84	80 (CO_2)	12	91.3	8	10	118	0	1	1	0.8
3403043......	5.60	80 (N)	12	92.7	10	10	75	0	0	0	0.0
Series IX											
3403007.	5.82	80	12	100.0	28	30	74	1	1	2	2.7
3403008 .	5.78	80	16	95.3	40	44	66	1	0	1	1.5
3403010 ...	5.57	Control		94.0	8	10	65	0	0	0	0.0

* More than 100 per cent due to potting error.

normal branching were not recorded for these field grown plants, but data for the seedling production, delay in germination, and for pollen abortion mutations in these series V to IX, are shown in table 5.

The controls for series V to IX, totaling 426 plants tested, gave no mutations. Since in series V only the 12 hour treatment yielded plants, this series is of no value for the purpose of extending the duration of treatment at 80° C. for which it was designed. The 12-hour treatment gave almost the same mutation rate as did the same treatment in series I (3.3 and 3.2 per cent respectively). No effect on the mutation rate was seen from seeds heated in an open bottle for 120 hours at 75° C. in a drying (vacuum) oven, so that drying took place (Series VI), although treatment at 5 per cent moisture and 75° C. for 20 to 40 hours induced mutations (Tables 2, 4, 5). Mutations might be expected from longer treatments in the vacuum oven. In no case were treatments at 60° C. long enough to induce mutations. Again longer treatments at this temperature might be expected to prove effective, although it remains to be seen whether or not seeds with the higher moisture contents would remain viable after longer treatments. Seeds at about 10 per cent or 15 per cent moisture succumbed when treated for a few hours at 75° and 80° C. As has been already pointed out, the seeds treated in atmospheres of oxygen, carbon-dioxide and nitrogen were subjected to the effects of drying as well as of the gases used. They produced but one mutation at temperatures and durations of treatment which should, had the seeds retained their initial water content, have produced about 3 per cent mutations.

From the tests of the relatively small number of plants of the Virginia race (Series IX), the indications are that this race differs but little from the standard Line 1 in its ability to mutate under treatment. The mutation rates obtained from it are not significantly lower than rates from comparable treatments of the standard line.

As was also found from aged seed experiments with *Datura* (4) most of the pollen-abortion mutations from heated seeds involved sectors of the plant in which they occurred. There were 54 of the gene type and 39 of the chromosomal type of mutations, or a total of 93 from the heated seeds. Nearly one-third of this number, or 29, extended throughout the

whole plant as far as tested. In 43 cases one-half of the plant was probably involved. The flowers recorded from one of the two main branches showed the mutation while those recorded from the other of the main branches showed normal pollen in 41 cases, while in one plant (341508, no. 79) one-half of the plant showed a gene type mutation while the other half had a mutation of the chromosomal type. In some of these plants further study might have shown that the mutant sectors were actually smaller than one-half of the plant. In 19 cases the mutations were expressed in only one of the four largest branches, or in one-fourth or less than one-fourth of the plant. The limits of two other mutations were not determined. The mutations which extend through the whole plant, or through one of the two main forks, should be found by our method of sampling the pollen from a flower on each of the two main forks. But mutations which extend through one-fourth or less of the plant may or may not be discovered. The chances for finding or not finding mutations in one-fourth of the plant are one to one, and if the sector is smaller the chances of finding it are correspondingly reduced. It may be supposed then that we have found less than 50 per cent of the smaller sectorial mutations that actually occurred.

The mutations which extend throughout the plant may be due to mutations brought in by either one of the parent gametes, and the possibility of this origin cannot be excluded for some of the 29 cases of such mutations in these experiments. However, the rate of mutations of this origin would not be increased by heat treatment of the seeds from which the tested plants are grown. There were no mutations found in the total of 892 control plants tested for these experiments, while the 29 mutations of this sort were recorded from the total of 7617 plants from variously heated seeds. It seems that most of these mutations, as well as the sectorial ones, must be due to the heat-treatment of the seeds. The embryonic plumule is already formed within the seed at the time of treatment, and the unfolding and growth of this organ produces the shoot of the mature plant. The extent of the

mutant sectors in the plant may give some evidence as to the amount of adult tissue that may be derived from single cells in the embryo, where, we suppose, the mutations arise. It is possible that injury and death of embryonic cells may lead to partial restitution of the growing points, so that a mutation in a heated seed may extend through a larger part of the adult tissues than would the descendants of a single embryonic cell in a normally developed plant. In the 29 cases under discussion the mutations extended, apparently, throughout the tissue layer which produces pollen grains in the whole of the shoots; while in the sectorial mutations they extended through this tissue layer in one-half, or one-fourth, or in a smaller portion of the shoots.

The effect on the mutation rate of environmental factors such as heat and moisture is of direct interest for the problem of the cause and nature of mutation. While, but a few years ago, it was generally supposed that mutation was both rare in nature and beyond the reach of experimental stimulation, it is now well known that a variety of experimental procedures may be successfully employed to induce mutations. These were at first strong radiation treatments, but it has become increasingly apparent that treatments more nearly related to the normal environment of the organism are capable of producing similar, though less extreme, effects. Heat is a factor in the normal environment, and one to which cells respond by quantitative or qualitative changes in their physiological processes. Navashin (14) has suggested that age and heat treatments operate to produce mutations through the alteration of the rate or character of the normal processes within the living cells. If this should be the case, then the mutations induced by age, heat, and the like, may be related in cause to those mutations considered natural or spontaneous. Increased mutation rates from aging seeds of *Datura* (4) may be explained as accumulation of mutations occurring at a more or less constant rate. Stubbe (19) presents evidence for accelerated rate of mutation with age in seeds of *Antirrhinum*. Heat, on the other hand, certainly increases the rate of muta-

tion; but the effects of age and of heat may be reducible to a time-temperature relationship which will include both treatments. It is of some interest to observe that the experimental determinations of normal mutation rates are usually made under carefully controlled conditions with fresh material. The increases of mutation associated with aging, high moisture content, and heating of the seeds suggest that conditions beyond the limits of carefully controlled experiments may be of importance for mutation rates in nature, and that these rates may be higher than "normal" rates found by experimental tests.

Summary

1. By heating *Datura* seeds under controlled conditions of moisture content, temperature, and duration of treatment, we have found that the seeds are killed beyond certain limits for each of these factors when the other two are held constant.

2. Seedling production was favored by moderate heat treatments, but fell off rapidly near the most extreme conditions endured.

3. The interval between planting and the appearance of the seedlings is increased about in proportion to the severity of the treatment.

4. Moderate and severe treatments caused abnormal growth, reflected in the types of branching of the plants grown from treated seeds.

5. Mutation rates, based on the pollen-abortion index, were increased by increased moisture content of the seeds, by increased temperature, and by increased duration of the treatments.

6. The highest mutation rates obtained by heat treatments of seeds in this material have not, so far, equalled the highest rates obtained by aging the seeds.

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INDIRECT SUGGESTION IN POETRY: A HINDU THEORY OF LITERARY ÆSTHETICS

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ABSTRACT

One of the most prominent of the several Hindu schools of literary æsthetic theory is that known as the *dhvani* school. It teaches that all literary art of the first rank contains *dhvani*—"tone, resonance, reverberation"—which is something that is not directly said in words, but indirectly suggested; and this "unsaid" meaning always (in first-class poetry) constitutes the prime source of æsthetic appeal. It is the purpose of the paper to outline the main points of the system as developed by the Hindus; to inquire whether and to what extent similar views have been expressed by western theorists; and to suggest that the doctrines of the *dhvani* school, with some modifications perhaps, could profitably be tried out by literary æstheticians of today.

> Jeden anderen Meister erkennt man an dem, was er ausspricht;
> Was er weise verschweigt, zeigt mir den Meister des Stils.
> Schiller, *Votivtafeln*, No. 49 (1796).

> The great literary artist is one who powerfully impresses a reader with an attitude of mind, a mood, a temper, a state of being, without describing it. If he describes it—if, that is, he anywhere injects himself into the process—the effect is lost.
> Albert Jay Nock, in *The Atlantic Monthly*, Sept. 1934, p. 279.

NEITHER of the two authors quoted above was aware that he was stating a well-known Hindu doctrine of literary æsthetics.[1] And yet I should find it hard, in a similar number of words, to express as well as Mr. Nock has expressed the very quintessence of what the Hindus call the theory of *dhvani*.

[1] Schiller could not have known this, for in 1796 that theory had never been heard of in Europe. Mr. Nock, in a letter to my student-assistant, Miss Irmgard Reader, dated 22 November, 1935, says that he had never heard of the Indian theory, and thinks it improbable that it "has at all affected Western literature, or even touched it" (in this I agree with him). He adds: "My own observation was casual, a mere obiter dictum that every one might make, and that I dare say has often enough been made before, though I do not know that it has. I thought it was something that any one of any literary experience knew quite well already—as I believe it is—and would at once recognize. . . . I cannot trace the substance of my observation to any specific literary source, nor can I suggest any instances in literary criticism that would serve your purpose. There may be such, no doubt there are, but I do not know them."

Dhvani is a Sanskrit word which means "tone." As used technically by a prominent school of literary theorists in India, it is applied to a type of poetry (or of literature; the Hindus regard the distinction between prose and verse forms as of little importance) in which the prima facie meaning of the words used is subordinated to another, deeper meaning, which is not "said," that is not conveyed by any words used in the text. This "unsaid" or suggested meaning is the dhvani, "tone, resonance, reverberation." And, by an easy transfer, the name dhvani is also applied to literature containing such a suggested meaning, provided that this suggested meaning is intended by the author and felt by the sensitive reader to be more important, more essential, as a source of æsthetic appeal, than the surface meaning of the words. All poetry (I shall henceforth use this word, following Hindu precedent, for literature, *belles lettres*)—all poetry of the first rank is dhvani. If the "unsaid," indirectly suggested meaning is felt as less important than the directly said meaning; that is if the poet—however great an artist in the mechanics of language—gives the impression of relying for his æsthetic effect more on his words or their surface purport than on their underlying "reverberation": such poetry belongs to the second rank only. Whereas if there is no suggested meaning, or none of any prominence or importance, the composition is dismissed as hardly meriting the name of poetry at all. To this third class is given the technical name *citra*, literally "picture," of which we shall speak again later.

Literary æsthetic theory, *ars poetica*, has a very long history in India. It seems to have developed first in connection with the drama. Technical treatises dealing with the art of dramaturgy seem to have existed as early as the first centuries of the Christian era, although it is doubtful whether any works preserved to us are as old as that. From about the sixth century on, we begin to find an extensive literature, not only on the drama but on poetic art in general. There were many schools and rival theories, and there was a good deal of polemic activity between them. The dhvani school, which interests us

now, never won universal acceptance. In later medieval times, however, it enjoyed a great vogue, and ultimately became, without any doubt, the dominant school of literary æsthetics in India.

It seems to have originated in Kashmir, not much before the ninth century. Our oldest full exposition of it is the Dhvany-āloka ("Light on the Dhvani") by Ānandavardhana of Kashmir, who lived in the second half of that century; his work is composed as a commentary on a somewhat older, and to us anonymous, collection of mnemonic verses, the Dhvani-Kārikās, which were intended merely to help a beginner to memorize the chief points of the system. These Dhvani-Kārikās (*kārikā* means simply "mnemonic verse") and Ānandavardhana's commentary on them are divided into four books, the first of which lays down in broad outlines the essence of the theory. In the very first verse we are told that dhvani is the "soul" of poetry; without it no poetry can truly live. It is something utterly different from the form and the direct, prima facie, "said" meaning of the words used. The words constitute the "body" of poetry, to which dhvani furnishes the "soul," the breath of life. Or, with a change of metaphor, dhvani is "like charm in a lovely woman," something different, as we all feel, from the physical, more or less analyzable beauty of each of her members, or of all of them together (i.4). The "body" of poetry can be scientifically analyzed by knowledge of grammar and the dictionary, plus prosody and the literary figures of sound or sense, the "adornments" of poetry, such as metaphors and the rest.[2] But dhvani, its soul, cannot be analyzed, just as according to standard Hindu philosophy the soul of living beings cannot be analyzed. It can only be felt directly by those cultivated and sensitive persons who understand its true nature by direct appreciation (i.7). It is only great poets [3] who possess the

[2] Which had been extensively analyzed and discussed by Hindu scholars for centuries before the rise of the dhvani theory.

[3] Ānandavardhana on i.1 says that all (real) poetry, "beginning with the Mahābhārata and the Rāmāyaṇa" (the two great classic epics), is dhvani; and throughout most of the work he is rather catholic in conceding the title dhvani at least to some individual verses of almost any competent poet, including some of his own compositions. The

power of using language in such a way as to evoke (in sensitive minds, of course) a "suggested" meaning over and above the primary meaning of the words (i.8).

This is not to say that the words themselves and their direct, primary meaning, are unimportant (i.9 and 10). As one who wishes to have light on his road must look to the wick of his lamp, since without a wick there will be no light, so the poet, wishing to suggest an unsaid meaning, must also, and even first of all, look carefully to the words he uses and to their prima facie meaning. The said meaning is a necessary prerequisite. Yet the suggested meaning remains the all-important thing, the prime source of æsthetic appeal, in poetry of the first rank. The relation of the two is compared (i.11 and 12) to the relation of the meanings of individual words to the meaning of a sentence as a whole. No one can fully grasp the meaning of a sentence unless he knows the meanings of all the words used in it. Yet those who really know the language in question do not, by separate acts of consciousness, form mental images of the meanings of each separate word, and then afterwards fit them together like a picture-puzzle. By the time the sentence is finished, its meaning as a unit flashes into the mind of the understanding listener. So the dhvani, the suggested meaning, flashes into the mind of the æsthetically sensitive listener, as soon as he grasps the prima facie meaning. It follows so quickly that he is usually not aware of any succession in time.

The commentary on i.4 develops the comparison with feminine beauty and charm in an illuminating way. The words used by poets, and their direct meanings, are as the parts of a woman's body; poetic figures of sound or sense (alliteration, metaphor, etc.) are like her jewelry and make-up.

Kārikā-author himself refers (i.5) to a verse of the Rāmāyaṇa as a standard example. But on i.6 Ānandavardhana says that "only two or three, or perhaps five or six, in the whole world" have deserved the name of truly great poets, by their mastery of dhvani; as an example he mentions here only Kālidāsa, who is by common consent accepted as the greatest Sanskrit dramatist and lyric poet. This is as if, in English literature, we said "only Shakespeare and a handful of others." Perhaps he means that not more than half a dozen Indian poets had regularly or constantly, in all their work, manifested such powers

Now physical beauty, even though not animated by that elusive something which we may call charm, or what you will —we all recognize it, even though we may be unable to analyze it—mere physical beauty is by no means negligible. A beautiful woman gives æsthetic pleasure, even if we call her beauty "doll-like." And external ornaments, skillfully used, may enhance beauty. So the dhvani school admits the æsthetic value of poetry which is musical in sound, of which the surface meaning presents appealing pictures, and which is skillfully ornamented with figures of speech, even though there be no "soul," dhvani, in it. Only, such poetry can never claim the highest rank. Ideally, of course, all these features should be combined in perfect art.

Before going into further detail in the development of the dhvani theory, a few examples should be quoted to show just what was meant. I shall choose them from Western literature rather than from that of India, since to use the original illustrations would require too much explanation for those who are not very familiar with Indian literature. And it will be convenient at the same time to broach the question of whether and to what extent the dhvani theory has parallels in Western æsthetic theories. Of influence, whether direct or indirect, there can in my opinion be no question whatever. Such parallels as exist must be attributed to fundamental similarities in the human mind. If any inference is to be drawn from them, it would at most be this, that if we should find very similar views widely accepted by Western students of the same field, it might raise a certain presumption in favor of the soundness of a theory which grew up independently in two such distinct environments.

That ideas comparable to that of dhvani exist in the west is undeniable. Among writers on poetics, one of those who comes closest to it seems to be Lascelles Abercrombie, who in his *Theory of Poetry* (1926) says that

> if we are to have an unusual degree of meaning in poetic language, it must be by means of its indirect or, as we say, its suggestive powers (p. 95).

And again:

> If a writer cannot invest his syntax with something of what we call the magic of words, we deny his right to the title of poet; but if he can make his individual words live in a special and unusual way in his verses, he may have scarcely any other power, but we allow him to be a poet. . . . For this purpose it will be enough if we agree that a writer, for his work to be accounted poetry, must be peculiarly intent on the *values* [author's italics] of his words in addition to their straightforward and explicit meaning (pp. 96–7).

What Mr. Abercrombie means here by the "magic of words" and their "values," contrasted with their "straightforward and explicit meaning," is clearly their "indirect or . . . suggestive powers," that is, dhvani. And in this passage he seems indeed to say that the capacity to use dhvani is the one and only absolutely necessary qualification for a poet. With it, though a man may have "scarcely any other power," he is a poet; without it, never. This is surely not far from what the Hindu school meant in calling dhvani the "soul" of poetry, and all else merely its "body."

Nevertheless, Mr. Abercrombie's book as a whole suggests, to me at least, that he would hardly go quite so far as our Indian school. And other writers on æsthetics and literary art seem rarely to have formulated the principle so clearly, and still more rarely to have attributed so much importance to it. One of the few statements I have yet found in English which may be taken as substantially the same as the dhvani theory is that which I quoted at the outset from Mr. Albert Jay Nock. Let me therefore borrow my first example from him. His article deals with Artemus Ward, who, Mr. Nock argues, proved himself a great literary artist by interpreting, criticizing, and illumining the life of his day, by the use in his writings of "indirection" (that is, dhvani). Here is a sample from Ward's account of a visit to Richmond after the fall of the Confederacy:

> I accompanied the African to my lodgins. 'My brother,' I sed, 'air you aware that you've been 'mancipated? Do you realize how glorus it is to be free? Tell me, my dear brother, does it not seem like some dreams, or do you realize the great fact in all its livin and holy magnitood?' He said he would take some gin.

This is a perfect example of dhvani. Please note that we must not confuse it with a theory of poetry which my interlocutors have often mentioned to me as parallel to dhvani, and which is well known in the West,[4] according to which great literature has something to say which *can* not be expressed in words. The dhvani is nothing so mystical as that. We shall see later that some dhvanis cannot, for very special reasons, be put into words; but this is not true of many, and certainly not of the one which Ward here employs. Mr. Nock himself states the meaning clearly and well, in these words: "A public movement launched under a pretext of liberation always breeds a monstrously inflated notion of the qualities of the people or class whom it is proposed to liberate." What is there in Ward's dhvani that is not conveyed by this admirably lucid and scientifically complete statement? Nothing, it seems to me. The point is not that it couldn't be said; it can. But a great artist can impress it on a sensitive audience much more forcefully by not saying it.

Or if you suggest that a passage from a satiric humorist proves little for serious art, take this example from Dante's *Inferno*, Canto v. Francesca tells of her guilty love, and how it arose from reading a book with her lover, more especially from reading one passage in it. Her speech ends thus:

> Galahaut was the book, and he who wrote it.
> That day we read no further in it.

What is there here that couldn't be plainly stated? Dante could easily have described what happened. He chose not to, because he knew that he could convey it more effectively by not describing it.

[4] See e.g. Kant, *Kritik der Urteilskraft*, § 49, and H. Brémond, *La poésie pure* (1926).

It has often been pointed out that Homer never describes Helen's beauty. He suggests it by dhvani, as in the celebrated passage [5] in which the Trojan elders, seeing Helen, say to each other that such beauty was worth all the trouble it had caused. Commentators since at least the time of Quintilian have observed that he thereby produces a more powerful effect on the reader than could have been produced by a description. In fact, Quintilian makes this passage the starting-point for a discussion of what seems to me substantially the same thing as dhvani, except that he assigns to it a quite minor place compared to that claimed for it by our Hindu school. With him it is only one of several kinds of *amplificatio* or *incrementum*, that is, rhetorical means of presenting a thing in a strong light; it is apparently not even the most important of these, for it is neither the first nor the last of his list, and another, mentioned earlier, is invidiously termed *incrementum potentissimum*.[6] Still, though a dhvani-writer would have thought that Quintilian failed signally to appreciate its importance, at least he seems to have formulated the principle:

> Illud quoque est ex relatione ad aliquid, quod non eius rei gratia dictum videtur, amplificationis genus (viii. 4. 21).

Then follows the above example, from the discussion of which it is clear that the remarks of the Trojan elders are "something which seems not to be said for the sake of that thing"; "that thing" is the depiction of Helen's beauty, which Homer desired to present powerfully (*amplificare* or *augere*). Quintilian adds several other examples, among them Vergil's indirect suggestion of the size of Polyphemus by saying that he used a pine-tree as a staff.[7]

Lessing in his *Laokoon* (xxi) refers to the same speech of the Trojan elders about Helen's beauty, in a way which superficially sounds like the dhvani theory. He says:

[5] *Iliad* 3.154 ff.

[6] viii.4.3.

[7] Another form of dhvani paralleled in Quintilian will be mentioned below.

> Eben der Homer, welcher sich aller stückweisen Schilderung körperlicher Schönheiten so geflissentlich enthält, von dem wir kaum einmal im Vorbeigehen erfahren, dass Helena weisse Arme und schönes Haar gehabt; eben der Dichter weiss demungeachtet uns von ihrer Schönheit einen Begriff zu machen, der Alles weit ubersteiget, was die Kunst (he means painting and sculpture) in dieser Absicht zu leisten im Stande ist. (He quotes the above passage, and adds:) Was kann eine lebhaftere Idee von Schönheit gewähren. . . ?

In other words, he says that precisely by not describing Helen's beauty, Homer knew how to give us a more powerful impression of it than a painter could give. Isn't this the dhvani notion? I thought so when I first read it. But a careful reading of the whole of this and the preceding chapters of the *Laokoon* will make it clear, I think, that Lessing's notion was fundamentally different. Lessing teaches that physical beauty needs to be presented all at once; that the effect of it cannot be produced by listing its elements one after another in time, as literature is forced to do; and that therefore its direct portrayal must be left to other arts. Literature can do it only by indirection. This is a variant of the doctrine mentioned above, that the great literary artist conveys something which words cannot, in the nature of things, say directly. Only because words are, in Lessing's opinion, incapable of performing certain functions, does he advise the writer not to try to use them in such ways. Utterly different is the dhvani theory, which makes the abstention from direct description a matter of choice, not of necessity, and by no means limits it to physical descriptions as Lessing does.

The contemporary German critic Alfred Kerr [8] mentions as a trait of modern realistic drama—

> das Streben, innerhalb des Dramas einen Kommentar zu vermeiden. Positiv ausgedrückt: Die Neigung, das Publikum Schlüsse ziehen zu lassen.

Here we have, I think, something very close to the dhvani

[8] In his book on *Das neue Drama* (1917): Anhang, Technik des realistischen Dramas, ix.

notion, though as in Quintilian's case it is not given anything like the importance which its Hindu advocates claimed for it; it is only one of a number of tendencies, all more or less on a par. One of Kerr's negative examples is so pat for my purpose that it is worth quoting. I take the liberty of paraphrasing Kerr in English. Lessing, though regarded as the "father of the realistic technique," did not think it possible to leave so much to his audience. As the Prince, in *Emilia Galotti*, is hurrying to meet Emilia in the mass, Camillo Rota comes to him. "What's the matter?" asks the Prince: "anything to sign?" "A death-sentence to be signed." "*Recht gern.*" For the feeling of our time (says Kerr—but also, I venture to suggest, for the feeling of most literary artists and sensitive readers of all times and lands), these two words are final. They suggest unsurpassably, without saying it (by dhvani), what Lessing meant this little scene to convey to the audience: namely, a trait in the character of the Prince. Lessing however is not content with them. As if he were afraid some one might not get the point, he has Rota explain it all in a monologue, after the Prince leaves the stage:

> Recht gern! Ein Todesurteil recht gern? Ich hätt' es ihn in diesem Augenblick nicht mögen unterschreiben lassen, und wenn es den Mörder meines einzigen Sohnes betroffen hätte. Recht gern! Recht gern! Es geht mir durch die Seele, dieses grässliche 'Recht gern'!

By telling the audience in plain words just what they are expected to feel, Lessing weakens the effect.[9]

[9] Lessing's procedure has been defended by some æsthetically gifted friends of mine on the ground that he meant to throw into higher relief the Prince's triviality by contrast with the humanity of an underling. But the speech is unnecessary for this purpose, since Rota's shocked surprise has already been made known much more effectively, by suggestion (dhvani), in a few words which I have omitted but which interested readers can easily find in the text. Hence I cannot feel that the defense is sound; but if it is, it would mean that Lessing renounced the opportunity for one dhvani in order to convey another which seemed to him (mistakenly in my opinion) more important. This consideration explains, and reconciles with the dhvani theory, the rôle of the chorus in Greek tragedy. Its reflections are not really violations of the principle; the statement sometimes made that the chorus expresses the feelings of the audience hardly does justice to the dramatists. The chorus, at least in Æschylus and Sophocles (Euripides sometimes misuses it), is in effect one of the actors, spiritually a participant in the drama.

There is, I take it, no doubt that most dramatists and dramatic critics of today would accept the principle of the unsaid meaning as a factor in dramatic art. How many would follow the dhvani school in making it the cardinal factor in all literary art of the first rank, I cannot say. A curious variation is found in the theory of the French dramatist and critic Jean-Jacques Bernard; for a succinct statement of his views see the preface to his collected dramatic works (*Théâtre*, I; Paris, 1925). A few phrases will suffice to show that, for the drama, he was at this time a thorough believer in dhvani:

> Le théâtre est avant tout l'art de l'inexprimé. . . . Il y a sous le dialogue entendu comme un dialogue sous-jacent qu'il s'agit de rendre sensible. . . . Un sentiment commenti perd de sa force. . . . J'ai été frappé de la valeur dramatique des sentiments inexprimés. . . .

The dhvani school would have applauded these opinions. But what would they have said to the following, from the same page?

> Aussi le théâtre n'a pas de pire ennemie que la littérature. Elle exprime et dilue ce qu'il ne devrait que suggérer.

Strange (would have been the Hindu comment) that he should not have seen that exactly the same principle applies to (non-dramatic) "literature" as to drama; the antithesis is wholly groundless. M. Bernard should have applied to all literature what was then familiarly known in France as *la théorie du silence* ("un peu trop simplement," as M. Bernard rightly protests, for "il ne s'agit pas de silence"; it is rather a question of the suggestive power of words to "mean" what they do not "say"). No literature ought to "express and dilute" what can be "suggested."

It is certain, I think, that other expressions of similar ideas will be found by continued search in western critical literature. I myself, without pretending to have examined all or even most of this vast field, have found other passages which remind one more or less of some aspects of the dhvani theory. When,

for example, Mr. I. A. Richards [10] emphasizes the distinction between "emotive" and "scientific" use of language, the former being specially characteristic of poetry, he is within the range of the *rasa*, the emotional "flavor," which we shall meet later as the most important manifestation of dhvani. I should appreciate information from interested persons as to other, and closer, parallels which I may have overlooked. I mean, of course, parallels to the theory, not examples of the use of dhvani in literature, which can be found on every page of good writers. However, the relatively meager results of my search so far seem to me to make two things fairly evident. One: the notion of dhvani, while by no means unknown, still less antipathetic, to occidentals of both ancient and modern times, has probably not often been brought out with full clarity by literary theorists. And two: still rarer appear to be westerners who are willing to attribute to it anything like the importance in literary theory which its Hindu advocates claimed for it.[11] While they may have exaggerated its importance, surely there must be a good deal in it, or modern westerners would not react to it in such a generally favorable manner as they seem to. I suggest that it would be worth the while of those who are interested in literary æsthetics to read something of what the Hindus say about dhvani. To tempt them further into the field, let me now outline some of the more important details of the system. I shall follow the spirit, and shall not depart far from the letter, of the Kārikās and Ānandavardhana.

[10] See his *Principles of Literary Criticism*, 1925, pp. 267, 273. The "emotive" use of language has been emphasized in recent years especially by what is called the Geneva school of linguistic science; see notably Charles Bally, *Le langage et la vie*.

[11] It has occurred to me to wonder whether one reason for this neglect may be the fact that in the West literary æsthetics is often treated as a part of general æsthetics, and theories are sought which will fit all forms of art; whereas this theory can, as it seems to me, be made to fit non-literary arts only with difficulty, by some stretching. I am aware that some authorities would differ from me in this, and would point to such doctrines as have been found in China (and elsewhere) with regard to painting: vacant spaces in a picture are said to "express" profound messages (see the article on Chinese Painting in the *Encyclopædia Britannica*, 14th ed.). But a blank canvas would "express" nothing, even in China. It is the whole composition that "expresses" whatever is expressed. And while there may be some kind of analogy between such painting as is here referred to and literary dhvani, I have some doubts of the value of the comparison. It would take us too far afield to discuss the question here.

There are various kinds of dhvani, and they are classified in several different ways: according to the way in which the suggested meaning is related to the prima facie meaning; according to the element in the text which effects the suggestion of dhvani; and according to the nature *per se* of the dhvani, the suggested meaning itself. I shall begin with the second. The dhvani-suggesting element may be a word,[12] a sentence, paragraph, or stanza, a longer passage, or an entire composition. The dhvani conveyed by a single word is substantially what Greek and Roman rhetoricians called *emphasis*, which means not what we understand by that term, but the use of a word in what we might call a pregnant sense, "giving it a content greater than that which the word has in itself," as Quintilian says.[13] Simple English examples would be: "Be a *man!*" "He has never *lived*." Here is a literary instance, from Shakespeare: [14]

Would you praise Cæsar, say '*Cæsar*': go no further.

The dhvani contained in sentences and brief passages has been sufficiently illustrated above. The dhvani conveyed by entire works, or lengthy sections of works (say chapters in a poem or story, or scenes in a drama) is, according to our authorities, always a *rasa*, "flavor, sentiment"; of this more presently.

Classified by its relation to the prima facie meaning, dhvani falls into two fundamental types.[15] In one the prima facie meaning is not really meant; in the other it is meant, but "exists for the sake of something else," that is its underlying

[12] See Kārikās iii.1 and 2 Even individual sounds may be "expressive," that is may involve dhvani, according to the theory accepted by the Hindus that to some extent there is an inherent affective content in sounds. This theory has also been held widely in the West, at least from the time of Dionysius of Halicarnassus (Ch. xiv; even Plato, Cratylus 240 C ff., has something similar), and down to the present day. Kārikās iii.3 and 4 deal briefly with this very minor matter.

[13] viii.3.83: altiorem præbens intellectum quam quem verba per se ipsa declarant. Quintilian perceived the affinity between this and the *amplificatio* mentioned above: Est hoc (sc. the kind of amplificatio which was referred to) simile illi quod *emphasis* dicitur; sed illa ex verbo hoc ex re coniecturam facit tantoque plus valet, quanto res ipsa verbis est firmior (viii.4.26).

[14] *Antony and Cleopatra*, Act iii, Scene 2.

[15] Ānandavardhana on i.16, end; ii.1 and 2.

artistic *raison d'être* is something not directly said in words. The first of these seems to relate only to dhvani of the single word, that is to what the Greek and Roman rhetoricians called "emphasis." At least the only examples given by Ānandavardhana are of single words. It is subdivided into two classes, in one of which the prima facie meaning is altered without being wholly annulled. The examples given are of the sort quoted above ("Be a *man!*" etc.). In the other the prima facie meaning is wholly annulled; this refers to the figurative use of words which could have no meaning if understood literally, such as "a *raging* torrent." It should be emphasized, however, that our authors were quite aware of the fact that such metaphors quickly wear out when used repeatedly, and that when worn out they no longer constitute dhvani. On this ground, as well as on the ground that other types of dhvani do not involve any figurative language, they insist that it is utterly wrong to identify dhvani with figurative language, as some of their rival schools did. The two things coincide only to a very minor extent; each often exists without the other.[16]

Much more important in our system is the second main division in which the prima facie meaning is meant, but "exists for the sake of something else." It includes all the major forms of dhvani, of sentences and of longer passages or whole works. It is also divided and subdivided in ways which are by no means devoid of interest. The principal division is into cases where the hidden meaning comes to the reader or hearer at the same time with the prima facie meaning, or at least without perceptible interval in time, and other cases where it follows perception of the prima facie meaning, "like the after-tones, reverberations, of a bell" (ii.24). The dhvanis quoted above from Homer, Dante, etc. belong to this latter class, as do

[16] Quintilian viii.3.83 ff. also treats "emphasis" as having two types: Eius duæ sunt species: altera, quæ plus significat quam dicit; altera, quæ etiam id, quod non dicit. The first of these is exactly the first of the two classes named above: the word "means more than it says." The second, however, is different: Quintilian means not figurative language, but rather the complete suppression of a word, or even of a phrase, by aposiopesis or the like. The Hindus would classify this as a form of dhvani of the sentence.

also the dhvanis of poetic figures (see just below). The former applies entirely to dhvanis of *rasa*, "flavor," to which we shall come presently.

Now for the third principle of classification, based on the nature of the dhvani *per se*. The suggested meaning may be of three kinds.[17] It may be a "thing" (*vastu*), concrete or abstract: that is an objective fact, an event or occurrence, an interpretative generalization, a principle or rationalization, or what not; in short, anything which could be said in words, except a poetic figure. All the dhvanis quoted in the first part of this article belong to this first category, and illustrate it sufficiently. Remember that they always could be said in plain words: the artist refrains from saying them not because they are "ineffable," but because he can impress them on the reader more powerfully by not saying them.

Secondly, the unsaid meaning may be a poetic figure, which also can of course be said in words, but may be indirectly hinted at as in veiled metaphors and allegories. It is separrated from the preceding type [18] on the ground that it rests on "the meaning of the words," rather than on "the meaning of the sense." That is, it seems to be regarded as dangerously near to a literary game. It is indeed a rather sophisticated type of dhvani, and tends to degenerate into literariness and preciosity, but within limits it may have æsthetic appeal. In its degenerate forms it would no longer be dhvani, since in them the unsaid meaning would be felt as "subordinate" to what is said, a mere ornament of the text. When the author gives the impression of being mainly interested in what he is saying directly, when he relies for æsthetic effect more on that than on the suggested meaning, we have by definition no dhvani. In dhvani the unsaid must be definitely dominant.

The third type of dhvani bring us to the concept of "flavor," *rasa*,[19] which is the most characteristically Hindu

[17] Ānandavardhana on i.4.

[18] See ii.24,25.

[19] The usual translation is "sentiment" (in German, "Stimmung"). So far as I know, "flavor" is original with me. But it seems to me a much more expressive and accurate rendering of what the Hindus meant by *rasa*. The literal meaning of the word is precisely "taste, flavor," as of food and drink.

part of the system, and hence the part most difficult to make clear to westerners. As our texts present it, this is also the most fundamentally important type of dhvani. They treat it as the only dhvani which may dominate, and be expressed by, entire works or lengthy sections of works. At the same time it may be found in short passages and single sentences or verses; even individual words, yes actually individual sounds, may affect it in a contributory way. Frankly, I feel it as a weakness, not in the principle of dhvani, but in its treatment by its Hindu advocates, that they attributed such overwhelming importance to this one type. Why for example should not the two other types just mentioned be found in entire works? Literary works which have a "moral," a *Tendenz*, are quite familiar to us, and are not usually on that ground alone denied the right to be considered works of art (even if we shy away from "propaganda" in art. and refuse to follow Tolstoi in considering such "lessons" the sole justification for it). Also works like *The Pilgrim's Progress* which consist wholly of an elaborate allegory, a dhvani of a metaphor, are known not only to us but also to the Hindus. They may not be the highest form of art, but is it not a bit inconsistent to admit dhvani of literary figures in subordinate passages, and ignore it in entire works?[20] If the theory is to be adapted for westerners, it might well be modified on such points as these. Perhaps however the "pure art for art's sake" school may regard this as a virtue rather than a weak point in the Hindu treatment.

At all events, let us try to see what the Hindus meant by "flavor," *rasa*, in literature. It is an old concept in India, not an invention of the dhvani school, and while this school

[20] These weaknesses in the system were noticed by Hermann Jacobi in *Zeitschrift der deutschen morgenlandischen Gesellschaft*, 56, p. 402 (p. 11 of the reprint), note 1. —Satire and irony, also, seem to be recognized by our school only in dhvanis of short passages. To us this is a defect; we think of *Gulliver's Travels* and *Erewhon*. As I write my eye chances to light on this passing remark by Joseph Wood Krutch in *The Nation* for April 1, 1936, p. 418: "The most admired, the most often read, and from the artistic standpoint the very finest part of Gibbon's history is comprised in those famous fifteenth and sixteenth chapters where he was compelled by the law against blasphemy to hint and imply what he dared not say. Nor is it by any means merely that he managed despite this law to convey what he wished to convey. The point is that he conveyed it *much more entertainingly and beautifully* (italics mine) than he would ever have done had he enjoyed complete freedom."

played an important part in its elaboration, it is accepted in essence by all Hindu literary theorists. It seems that it was first applied to the drama, where it is most obviously at home. It means the emotional content of a literary work, especially a drama; successfully handled by a true artist, it manifests itself in corresponding effects on the emotions of the audience. Eight or nine principal "flavors" are recognized; they correspond item for item to eight or nine primary "states" or emotions,[21] in the following schematic way:

The "erotic" flavor corresponds to the emotional state of love.
The "heroic" flavor corresponds to the emotional state of "energy, courage."[22]
The "furious" flavor corresponds to the emotional state of wrath.
The "pathetic" flavor corresponds to the emotional state of sorrow.
The "comic" flavor corresponds to the emotional state of mirth.
The "marvelous" flavor corresponds to the emotional state of wonder.
The "fearful" flavor corresponds to the emotional state of terror.
The "loathsome" flavor corresponds to the emotional state of loathing.

Only these eight are allowed in the drama. There is a ninth, the "tranquil" flavor; it corresponds, we should say, to absence of any emotion. The Hindus naturally thought of it as corresponding to the emotional, or rather emotionless, state of the holy man, the world-renouncing ascetic or saint, whose

[21] The Hindus have no word which really renders "emotion." As near to it as any is *bhāva*, which is so translated here; it actually means "condition, state of being," and is therefore a considerably broader concept. The eight "states" named above are not supposed to be the only human emotions. The dramaturgical theorists, in fact, list no less than thirty-three "states" (not all of them would be called "emotions" by us), which are termed "concomitant states"; literary theory recognizes no "flavors" in literature corresponding to them. Only the eight or nine mentioned above are called "fixed" or (relatively) "permanent" states, because man is apt to remain characterized by them for a considerable time. The others are mostly more transient, and are held to be of secondary importance.

[22] What is meant is the emotional "state" which characterizes a "hero." I am not satisfied with any English rendering that has occurred to me; "energy" is the one commonly used. But Jacobi used the German word *Mut*, "courage," which seems to me better.

first duty is to overcome all emotions. Naturally it is forbidden to use it in the drama; it is inherently opposed to the very nature of the drama. No one goes to the theater to be lulled into a trance-like state of lack of feeling. But it may occur in other literary works.

Some one "flavor" must be dominant in every drama as a whole. In the types of drama which the Hindus regard as primary and of first importance, the dominant flavor must always be either the erotic or the heroic. In simpler words, the play must be either a love-story or a story of adventure. (Other flavors, notably the comic, may dominate in minor forms of drama.) But since the piece would be monotonous if the same flavor prevailed throughout, others than the dominant flavor may and even must be introduced in episodes, always judiciously, in such a way as to heighten the ultimate effect by contrast.[23]

How does the dramatist produce the desired flavor in his drama? The following is the Hindu theory. The emotions to which the flavors correspond must be imagined as felt by the characters on the stage; particularly the dominant emotion as felt by the principal characters. Since no one can directly depict an emotion, the dramatist depicts the "factors" which produce the emotion, and the "effects" which are the outward manifestations of its existence in a character. The "factors" are of two kinds: the "basis," and the "excitants." The "basis" of love is the loved person; the "excitants" are spring, moonlight, etc. The "effects" of love are roughly comparable with those which we conventionally recognize as signs that a person is in love. In the Hindu works on dramaturgy, all these things are schematized, in what I must admit is pretty pedantic detail, for the more important emotions, particularly love. And the theory was later applied with slight adaptations to other forms of literature.

[23] Some flavors are so inherently contradictory that one cannot be tolerated at all in a composition dominated by the other: such at least is the accepted Hindu doctrine, though most of us would probably think it too sweeping. Thus the loathsome flavor would ruin the erotic, say the Hindus, and cannot be admitted, even episodically, in a love-story; while it may well be used to heighten the effect of the heroic flavor in a story of adventure.

By depicting the "factors" and the "effects," then, a skillful dramatist suggests the existence of emotion in his characters. If he succeeds in this object, the effect is transferred to his composition, as a "flavor," which is "tasted" as it were by the sensitive, appreciative audience. Note that in this case, it *must* be done by indirection, that is by dhvani. For, as Ānandavardhana points out, by merely saying the word "love" you will never produce the flavor of love in your poem. It is only the factors and effects, not the emotion itself, which can be described.[24] To this limited extent, then, and for very special reasons, the dhvani theory comes into partial agreement with the western doctrine that poetry expresses something which "cannot be said in words."

The theory of the "flavor," as something always "unsaid," makes it possible to assume a suggested meaning in practically all literature, and so opens a very wide field for dhvani. It is hard to find anything that can be called literature which has no "flavor," no emotional content, at all. In theory our school recognizes the possibility of such writings, in its third and lowest type of poetry, to which it gives the curious name of *citra*, literally "picture." It is treated briefly [25] as "not true poetry at all, but only an imitation of poetry." That is why it is called a "picture," because it only simulates real poetry and has no "life" of its own. It reveals at most mere technical versatility, not true talent. Ānandavardhana goes on to say that "nowadays," in the advanced stage of culture and enlightenment then prevailing, perhaps some apprentice-work may be classed as *citra*, but no mature poet composes anything that doesn't have some suggested meaning, some emotional content or "flavor" at least, if no other kind. But let it not be forgotten that the possession of "flavor" is in itself not enough to qualify a composition as dhvani, genuine first-class art. Again and again our texts remind us that in order to

[24] The apposite remarks of Ānandavardhana form the last part of his commentary on Kārikā i.4, a difficult and obscure passage which Professor Jacobi does not seem to me to have rendered very successfully. I have given a good deal of study to it, and hope that I have correctly interpreted its purport.

[25] In iii.43.

merit that designation poetry must be felt as revealing a suggested meaning which is definitely dominant. If the reader feels that the words used, and their prima facie meaning, are the main source of æsthetic appeal, then, even though there is also some "flavor," the piece is only second-class poetry. It is perhaps invidious and dangerous to mention names, but I venture to suggest that some of the poems of Algernon Charles Swinburne, and some of the prose of Robert Louis Stevenson, would be placed in this category. If any doubt is possible as to the relative æsthetic interest, if the suggested meaning is only approximately equal in æsthetic importance to the prima facie meaning and its verbal expression, there can be no question of dhvani, but only of poetry "in which the suggested meaning is not the main thing." [26]

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[26] The Sanskrit text of the Dhvani-Kārikās, with Ānandavardhana's commentary, and also with a subcommentary by Abhinavagupta of Kashmir (end of the tenth century), was published as Vol. 25 of the series called Kāvyamālā, Bombay, 1891. It has been translated into German, with an introduction, by Hermann Jacobi in a series of articles in the *Zeitschrift der deutschen morgenländischen Gesellschaft*, Vols. 56 and 57; collected and reprinted in pamphlet form, Leipzig, 1903. A brief treatment in English is found in A. Berriedale Keith's *History of Sanskrit Literature*, Oxford, 1928, pp. 386 ff.; a more extended treatment in Sushil Kumar De, *Studies in the History of Sanskrit Poetics*, 2 volumes, London, 1923 and 1925. All these treatments, I regret to have to say, seem to me to suffer from overtechnicality. They are useful to Sanskritists in that they help to interpret the often obscure and difficult original texts; especially Jacobi's work has been thus helpful to me. But a non-Sanskritist would not find it easy to extract from any or all of them the real essence of the theory. Perhaps that is why so little attention has been paid to it.

I have practically ignored the linguistic speculations of the school, to which western scholars (following the original texts I admit) commonly attribute a good deal of importance, but which seem to me merely *ex postfacto* rationalization. The notion of dhvani was brought into relation to a linguistic theory of the Hindu grammarians, according to which behind every word in actual speech there is what is called a *sphoṭa*, a kind of ideal prototype of the word. There was also a good deal of theorizing as to the various kinds of "meaning" which words may have. The grammarians usually distinguished two kinds only, direct or primary, and figurative meaning. The dhvani school postulates a third, "suggested meaning," which is the basis of dhvani in a word. All this doubtless seemed important to them; and in so far as their distinction between "figurative meaning" and dhvani has real practical value, I have dealt with it above. But it is to their credit that as soon as they get down to their real business of interpreting poetry, they do not let themselves be led astray by such linguistic theories, which have for us little more than historic interest. To me, therefore, it seems that the introduction of such speculations only beclouds the issue, and tends to minimize the genuine merit of the school, which consists in its realistic and unprejudiced attempt to analyze the basis of æsthetic appreciation of literature.

SHAKESPEARE'S SEVENTEENTH CENTURY EDITORS

MATTHEW W. BLACK

(*Read April 23, 1936*)

Abstract

Even the great Dr. Johnson, maker of the first authoritative English dictionary, and one of the best-known of 18th century Shakespeareans, was sometimes wrong, and —sometimes—admitted it. He is said to have explained a mistake in his dictionary, the definition of a horse's pastern as its knee-cap, as due to "ignorance, sheer ignorance." Perhaps his reply would be the same if he were asked why he once wrote, "Whoever has any of the [Shakespeare] folios [i.e. 17th century collected editions] has all, excepting those diversities which mere reiteration of editions will produce." Analysis of the textual difference between the successive folios of 1623 [the first], 1632, 1664, and 1685, reveals a consistent and successful effort to improve the text, on the part of editors employed by the printing houses. The folio of 1632 contains some 1600 attempted improvements, nearly two to a page; that of 1664, 900; that of 1685, 700. These alterations range in character from modernizations of the diction to conjectural restorations of Shakespeare's words where the printer had garbled them. About half of all these emendations appear *literatim* in the standard modern texts, and only a tenth of them can be called really mistaken. The men who made them deserve the proud name of Shakespeare's first editors, and if not the most thorough, are not the least brilliant of them all.

The collected plays of William Shakespeare were published four times in the seventeenth century: in 1623, 1632, 1664, and 1685. The four editions are alike in format, being folio volumes of about 900 pages, thirteen inches tall. The first, or 1623, folio is obviously the most important, since it was closest to the actual manuscripts which came from Shakespeare's pen; but it is a highly imperfect piece of printing, apparently run through the press without adequate supervision. As to the three succeeding folios, scholars for nearly two centuries—until a decade ago—were for the most part content to repeat the opinion of Dr. Johnson: "The truth is that the first folio is equivalent to all the others and that the rest only deviate from it by the printer's negligence. Whoever has any of the folios has all, excepting those diversities which mere reiteration of editions will produce." A century and a half later, in 1922, Miss Henrietta Bartlett, a

noted American bibliographer of Shakespeare, writes that "the second folio has no new readings which are of interest to the scholar"; and as late as 1925, one of the best known of Shakespeare's biographers, Sir Sidney Lee, allows the following to stand as his verdict: "The second folio was reprinted from the first. A few corrections were made in the text, but most of the changes were arbitrary and needless and prove the editor's incompetence." Folio three, he continues, is "mainly a reprint of the second," and the fourth "reprints the folio of 1664 without change except in the way of modernizing the spelling, and of increasing the number of initial capitals within the sentence." A few investigators have from time to time expressed the conviction that the work of editing began in the three later seventeenth century folios, especially the second, but no complete account of the extent and value of such textual supervision has so far been set forth.

During our collations of the texts of the *Second Part of King Henry IV* and *Richard II*, respectively, my colleague, Professor Matthias A. Shaaber, and I arrived independently at the conclusion that more, and more important, editorial work had been done on the texts of the three later folios than had as yet been recognized. Believing that a full statement of the facts was a desirable and indeed a necessary preliminary to further work on the text of Shakespeare, we entered, in collaboration, on the preparation of such a statement. We examined in detail the differences recorded in the Cambridge Shakespeare and the Furness Variorum, between the first and second, the second and third, and the third and fourth folio editions, and set down the conclusions to which these differences logically lead, as to the minds employed in the editing of these texts, the equipment which the editors brought to their task, and the value of the changes they made in determining the final text of Shakespeare's plays. The purpose of this paper is to present a brief outline of our method and of one section of our results.

The raw material of our study was a great many thousand

slips of paper on which were transcribed parallel passages from one folio and its successor, in which a textual difference, or differences, appeared. Upon picking out from the mass a hundred passages at random, we perceived at once that the great majority of the changes were wrong, not because they reduced intelligible words to nonsense—*that* we could safely blame on the printer—but because they altered unnecessarily passages which made perfectly good sense, presumably the sense which Shakespeare intended. Such alterations seemed to raise the question, were these men, whose minds and methods we have set out to recreate, madmen, who with a flash of insane brilliance corrected one passage and then for no reason at all ruined a dozen? Our first step out of this impasse came with the realization that, in company with most other editors of the last two centuries, we had underestimated the havoc which a printer can wreak, when he is operating a hand press, probably under pressure of time. The seventeenth century printer had first to memorize a portion of his copy, then turn to the type-case and make up his line letter by letter, then place it in the form—all presumably without another glance at his copy, unless he was conscious of forgetting. It was a highly laborious process, greatly dependent on memory, and very different from setting type with one's eyes upon the copy and one's fingers upon the keys of a linotype machine. Errors due to poor light, bad eyesight, turned type, and type that dropped out of a badly locked form and were replaced improperly are the obvious possibilities. To them, however, must be added errors due to failure of memory and to unconscious verbal association during the all-important interval after memorizing, and while setting up. Thus under seventeenth-century printing conditions, typographical errors must have been many times as numerous as they are today, and infinitely less obvious. With this conclusion in mind, we were able to jettison at one stroke a good half of the passages we had assembled, and, in our judgment, to clear Shakespeare's seventeenth-century editors of the worst crime which has been alleged against them, namely,

arbitrary changes in the text. To be sure, there remained certain changes for the worse in which we could see a purpose —distorted and mistaken, perhaps, but still a purpose. These we retained.

Including mistaken changes made deliberately, there now remained some 3200 passages in which we believed that we could clearly see the hand of an improver of the text, an editor. Of these about 1600, nearly two to a page, occurred in the second folio, 900, or one to a page, in the third, and 700 in the fourth.

We next collated these passages with the Cambridge and other standard modern texts, and tabulated the results. We found that on the basis of the accepted modern readings, only a small proportion of the folio changes, about one in ten, could be considered really mistaken. On the other hand, about half of them are exactly adopted by present-day authorities. Others revealed the folio editors in the process of detecting "cruxes" which have given constant trouble to later interpreters, and taking timid steps toward emending them, which have been superseded by bolder steps on the part of later editors. Still others, though not in the standard modern texts, had been adopted by a minority of later editors, and these it seemed unfair to stigmatize as entirely mistaken. All in all, we believe our figures will amply demonstrate that many of the editors whose names are known and revered contributed less to the establishment of the true text of Shakespeare than did these nameless seventeenth century revisers.

Granting that the things they omitted to do would fill a still larger volume than ours, here are some of the things they did: they supplied omitted words necessary to the meaning; they corrected inconsistencies of fact and circumstance; they corrected unobtrusive corruptions of the text; they emended glaring corruptions by inspired guesswork; they rectified stage directions; they ironed out any number of mistakes in grammar; they restored the rime in defective riming passages, and they modernized the style.

If it be objected that this was routine work which any intelligent master-printer might have been responsible for, let us examine that section of the changes in which nothing short of brilliance will suffice: I mean the emendations by inspired guesswork. It seems to us that none save the hierarchy of Shakespearean editorship—Theobald, Steevens, Capell—excel the folio editors in brilliance. In thoroughness, yes—though it must be remembered that the modern critical method of textual collation had not been developed in the seventeenth century; but not in brilliance. Let us consider a few examples of their achievements. In *Romeo and Juliet*, Romeo kills in a duel one Tybalt, kinsman to the Prince of Verona. The Prince banishes Romeo upon pain of death if he returns. He might have ordered Romeo's immediate execution; he might have pardoned him. Instead, he banishes him. In defending his choice of a punishment he says, according to the first folio:

> And for that offence,
> Immediately we do exile him hence:
> I have an interest in your hate's proceeding,
> My blood for your rude brawls doth lie a-bleeding;
> But I'll amerce you with so strong a fine
> That you shall all repent the loss of mine:
> I will be deaf to pleading and excuses;
> Nor tears nor prayers shall purchase out abuses,
> Therefore use none: let Romeo hence in haste,
> Else when he's found, that hour is his last.
> Bear hence this body, and attend our will:
> Mercy not murders, pardoning those that kill.

The passage always makes me wish the Prince of Verona could have lived to comment upon the decisions in certain American criminal trials. His anger is personal as well as civic, and his expression of it eloquent and passionate. The imperfection of the passage is one which could hardly be detected except by someone with a taste for dramatic speech. The fault lies in the last line: not in its meaning, for its meaning is perfectly intelligible. "Mercy not murders, pardoning those that kill": mercy in Verona does not pardon those that

kill, for that is tantamount to another murder. It was with the tone of the line that our editor was dissatisfied: it sounds tame, defensive, explanatory. Why, after the majestic imperative, "Bear hence this body and attend our will," would the deeply moved prince weakly explain his reason for punishing the murderer? He would not do so. But what would he do? The folio editor, by changing just two letters, turned the tame explanation into a bold, striking metaphor:

Mercy *but* murders, pardoning those that kill.

Moreover, this reading has appealed to practically all later editors as almost certainly what Shakespeare intended, and so is printed in all of the standard modern texts. It may be objected that in the fourth act of *Hamlet*, Laertes' (first folio) comparison of himself to "the kind, life-rendering Politician" is self-evidently wrong. The difficulty was, what word beginning with *p*, ending with *n*, and containing an *i*, an *a*, and a *c* fitted Laertes' meaning? Out of a mind well-stored with literary allusions and gifted with imagination, the reviser produced the idea of the pelican, which was traditionally supposed to feed its young with fragments of its own flesh. And what of "the base Iudean" in *Othello?* Would any save a mind well fitted for the task of literary emendation have failed to accept this as an historical allusion, to Herod, perhaps, and have substituted the true reading "the base Indian"? The 353 accepted rectifications of the metre of the first folio achieved by the editor of the second show both ingenuity and an ear for rhythm which a poet might not shame to own. In the Induction of the *Taming of the Shrew*, for example, the reviser was not satisfied with the line

And not a tinker, nor Christópher Sly.

because it throws an improper accent on the second syllable of Christopher. But he remembered that in one—and only one—of the two prose speeches in which Sly gives his full name, he adds a drunkenly grandiose extra syllable to Christopher, making it Christóphero. The editor's sensitive ear told him that the pronunciation Christóphero would

smooth out the metre of the present line, and so he added the syllable here, even though it meant changing the verse from the regular ten syllables to eleven:

> And not a tinker, nor Christóphero Sly.

The reviser's occasional correction of the proper names in literary and historical allusions is also interesting. For instance: to see *Hyperion* rising in the east where the first folio prints the sun-god's name as *Epton* argues some knowledge of mythology. Thus even a brief review of the work of the editor of the second folio gives the impression—which is greatly strengthened by the evidence in full—that he was a man of considerable parts. At all events, no one can reasonably argue that he did not exist. More than 800 emendations accepted by modern editors do not find their way into a text in a single edition through the irresponsible improvisations of type-setters and proof-readers. That his emendations make a substantial contribution to the standard text of Shakespeare is self-evident.

The performance of the editor of the third folio was limited by the fact that the editor of the second had been before him. There was less for him to do, except in the matter of correcting new mistakes made by the printers. As a result, there are fewer brilliant emendations in the 1664 volume. Though the editor may have been quite as alert as his predecessor, he was probably inferior in literary judgment. Certainly he is responsible for the drollest exhibition of mistaken ingenuity which we have yet uncovered—completely mistaken, to be sure, but still highly ingenious, and therefore tending to bear out our initial contention as to the deliberateness with which these changes were made. In the *Merchant of Venice* the second folio makes young Gobbo say, "Sola, did you see M. Lorenzo, and M. Lorenza?" M. Lorenza is a typographical error for M. Lorenzo, whose name is simply called twice. The *and* is also an error. But to the editor "and M. Lorenza" looked like the feminine form of Lorenzo's name, and so he changed it—to "*Mistress* Lorenza." It

must be admitted that this does less credit to the editor's critical handling of the text of Shakespeare than to his romantic interest in the wedding of Shylock's daughter to Lorenzo; but so logical a change can hardly be due to the ill-starred activities of the printer. Aside from correcting a good proportion of the new typographical errors made by the careless printer of the second folio, the 1664 editor shows the first glimmerings of consistency in the spelling of proper names, and he is at considerable pains to substitute current expressions for those which by 1664 sounded archaic or inelegant. Altogether, his volume is a far more efficient and creditable editorial performance than any critic has as yet recognized.

The fourth folio is the most readable text and the most workmanlike piece of printing of the four. The spelling of the text is in general brought up to date, and considerable consistency of typographical practice is achieved, especially in the use of italics, the placing of stage-directions, and the use of initial capitals. The punctuation is improved in many ways. Yet even an editor whose mind was fixed on the job of printing, not on the text of the plays, whose primary object was to produce a creditable specimen of the printer's art, a book that buyers could read with ease, was capable of introducing over 300 successful emendations into the text, one of them certainly the most brilliant of any achieved by a folio editor. This occurs in the play of *King Richard III*, act four, scene one, lines 92–95, where the first folio makes the Duchess of York speak as follows:

> Go thou to Richmond, and good fortune guide thee;
> Go thou to Richard, and good angels tend thee;
> Go thou to sanctuary and good thoughts possess thee;
> I to my grave, where peace and rest lie with me.

In the second folio the first line reads "Go to Richmond, to Dorset, to Anne, to the Queen, and good fortune guide thee." The words inserted in the second folio indicate the several persons to whom the first three lines of the Duchess' speech are addressed. To Dorset, the Duchess says, "Go thou to

Richmond." To Anne she says, "Go thou to Richard." To the Queen she says, "Go thou to sanctuary." What must have happened is that the editor of folio two, perceiving the need of indicating to the reader the persons successively addressed by the Duchess, wrote the directions in the margin of the copy of the first folio which he was preparing for the printer, indicating that they were to be set up in italics, one after each of the three first lines of the speech, like any other stage directions. Thus, if the italics are read as handwriting, the copy sent to the printer of the second folio must have read as follows:

> Go thou to Richmond and good fortune guide thee; [*to Dorset*
> Go thou to Richard and good angels tend thee; [*to Anne*
> Go thou to sanctuary and good thoughts possess
> thee; [*to the Queen*

But the compositor, mistaking the intention of these marginal notations, perhaps because of cramped handwriting, huddled them all together in the first line after the parallel phrase "To Richmond." The third folio reprints the second without change.

The editor of the fourth folio triumphantly restores these stage directions to the margin, each after its proper line, and in addition supplies the word "thou" omitted by the 1632 printer who garbled the line. One's first thought is, "Here, for once, the editor must have consulted the previous edition." But an instant's reflection reveals the extreme unlikelihood of any such explanation, for he would have had to consult the very copy used by the reviser in a different printing-shop more than half a century before. And if we grant that by some chance he could have done so, the new and still more difficult question arises of why, having this volume in his possession, and having obtained one valuable piece of assistance from it, he failed to take advantage of its help in any one of a thousand other passages which must have puzzled him. We are forced to conclude that the 1685 proof-reader, reviser—call him what we will—un-scrambled the stage-directions by the light of pure common sense, and supplied

the "thou" by analogy with the succeeding lines; and it seems to us undeniable that in so doing he constituted himself an editor in the fullest sense of the word.

A detailed examination of all the facts about all of the folios, of which a few specimens are given here, leads to the conclusion that the three later folios are not imperfect reprints of their predecessors, but critical editions in the same sense and to the same degree that Rowe's work of 1709–10 is a critical edition; that the persons responsible for their preparation treated the text on the same principles as did Shakespeare's alleged first editor, introduced just as many good changes, and overlooked no more numerous corrupt passages that called for emendation. The folios are not critical editions in the fullest sense of the word because their editors had not hit upon the device of scientific comparison of texts. Their work is guesswork. They had nothing to go on but their own intelligence, their knowledge of the past, and their acquaintance with the language and customs of the time and with the stage presentation of Shakespeare's plays in their own day. But we believe that in revising the text at the prompting of their own intuition the seventeenth century editors were doing as much as could be expected according to the standards of their age. And we submit that the history of the text of Shakespeare must be revised by placing them on much the same footing as are their immediate successors.

Unfortunately, the most interesting question of all concerning the editors, namely, who they were, seems unlikely ever to be answered. The only conjecture we venture to indulge in is that the editors of the third and fourth folios were professional proof-correctors; though they produced brilliant emendations upon occasion, they constantly betrayed their pedantry, lack of imagination, and deafness to rhythm. The editor of the second folio seems to us an entirely different kind of person. We cannot think that he was the corrector regularly employed by the printing-house, for if he had been, it seems incredible that after taking such pains with the text, he would have been content to let the book issue from the shop

with so many bad misprints. What is more, he shows an appreciation of the plays as drama and as verse which the later editors match but seldom. His work taken as a whole displays greater imagination and finer literary tact than theirs, together with a certain unprofessional obliviousness to the functions of a mere corrector. With his knowledge of history and the classics, his ability to visualize the action of the play, and his ear for rhythm, the editor of the second folio naturally invites speculation about his identity. Small wonder that one Shakespearean, bolder than the rest, suggested Thomas Randolph, the brilliant young "son of Ben Jonson" as the man, or that the admiring German critic, Tieck, as George Ticknor tells us in his *Life, Letters, and Journals*, "thought Milton superintended the edition . . . because changes and emendations made in it upon the first folio are poetical and plainly made by a poet." Whoever he was, we should be glad to think that our work has had the effect of making known the precise extent and quality of his achievement, for he holds the enviable position of Shakespeare's first editor, and by no means the least brilliant of them all.

SHAKESPEARE IN PHILADELPHIA

HENRY N. PAUL

(Read April 23, 1936)

ABSTRACT

Shakespeare's theme in his great tragedies is the rise and fall of great or noble men. The immense influence which he has exercised warrants inquiry as to how knowledge of, interest in and study of his dramatic works began in Philadelphia, for this city was the gateway through which the Works of William Shakespeare made their entrance into America.

His influence during our Provincial period was not widespread; but immediately after the Revolution there was published in Philadelphia the first Shakespearean poem by an American, the first Shakespearean play published in America, the first Shakespearean portrait by an American, and the first Shakespearean book published in America. In 1795 the first American edition of his complete works was published in Philadelphia under the care of Joseph Hopkinson. At the beginning of the century competent representations of his plays were given in Philadelphia, and thus was created a large body of persons who read his works and saw his plays

Here in Philadelphia grew up Edwin Forrest, the first really great American actor. And here first, at the University of Pennsylvania, were established special courses of lectures on the Shakespearean drama as part of a college course.

In Philadelphia in 1852 was formed the first Shakespeare Society in America which has continued until today; and among the members of this society was Dr Horace Howard Furness, the editor of the New Variorum Shakespeare, who has furnished the admirers of Shakespeare's plays with an apparatus for scholarly investigation not elsewhere to be found.

There is possible danger in the modern use of Shakespeare's plays as classics, in place of the ancient classics, should there develop a tendency to study him by rule; for this does not accord with the free spirit in which his plays were written. The best antidote to this is the *New Variorum Shakespeare*, where the study of his work is enlightened by fine scholarship and based not upon the microscopic but upon the broader human interest.

DURING the first part of his work as a playwright when William Shakespeare was to produce a new play he usually sought suggestion for his theme or story either in one of the old plays which had found favor with London audiences, or in the *Chronicles of England* by Raphæl Hollinshed.

But in midcareer he came under the influence of something much more stimulating. About 1599 William Shakespeare began to study with care *Plutarch's Lives of the Noble Grecians and Romans* in the lively, racy translation of Sir

Thomas North, printed in a splendid thick folio volume by Shakespeare's old Stratford friend, Richard Field. He founded four plays on what he read in this book. What is still more important, the ideas of this book influenced his art just as he was beginning to write the series of great tragedies which have made his name familiar to all the world.

He must have read many times North's address to the reader with which this volume begins. It is an upholding of the "*profit* of stories," by which Sir Thomas means biographical pictures of great men, as the most powerful influence which letters can exert upon human life. As to this he says:

"All other learning is private, fitter for Universities than Cities, fuller of contemplation than experience, more commendable in students themselves than profitable unto others. Whereas stories are fit for every place, reach to all persons, serve for all times, teach the living, revive the dead, so far excelling all other books as it is better to see learning in Noble men's Lives than to read it in Philosophers' Writings."

Here is expression of a notable truth! Not laws, not formulæ, not institutions, but persons most influence our lives.

Under Plutarch's influence William Shakespeare thereafter pictured the rise and fall of great or noble men, showing us both the noble substance and the "dram of eale" which caused their downfall. This was his interpretation of the human tragedy; and these pictures skilfully cast by him into moving dramatic form, and dressed by him in the most exquisite poetry, have so powerfully affected human thought that it would seem fitting, on this his birthday and here in the heart of Philadelphia, to enquire how knowledge of, interest in and study of Shakespeare's dramatic works began in Philadelphia. This is the more interesting because this city was the gateway through which the works of William Shakespeare made their entrance into America.

During our provincial period Shakespeare, and indeed the drama generally, seems to have exerted but little influence here. Our colonial forefathers did not favor the stage, and

when they went into print they busied themselves chiefly with either politics or theology.

Here and there a copy of the works of Shakespeare was to be found in the bookcase of some gentleman's library. James Logan had in his library at Stenton a copy of Rowe's *Shakespeare* dated 1714, probably purchased soon after that date. The Library Co. of Philadelphia purchased a set of Hanmer's edition of *Shakespeare* in 1746. George Washington possessed a set of Bell's edition of *Shakespeare.* Of the Signers of the Declaration of Independence, we know that John Adams of Massachusetts, Francis Hopkinson of Philadelphia, and John Penn of North Carolina, and doubtless others, owned such sets.

There was occasional representation of his plays on the stage. A good while before the Revolutionary War, at the old Theatre in Southwark (as near Philadelphia as our city fathers would permit) Hamlet and Macbeth received their premier performances in America by Hallam's Company. But the Quaker influence frowned upon these doings, and the war put an end to them.

Soon after the Revolutionary War ended, however, we note certain small but promising signs that renewed interest in the Shakespearean drama is arising in this country.

In 1787 Peter Markoe of Philadelphia published a volume of *Miscellaneous Poems* including a long and heavily-laboured Ode on the Tragic Genius of Shakespeare, the first Shakespearean poem printed in America. In the same year was published in this city a play of Shakespeare—"The Twins"—a shortened version of the Comedy of Errors.

And still in the same year an engraved portrait of Shakespeare's statue in Westminster Abbey appeared in Philadelphia as the frontispiece for the *Columbian Magazine* of July 1787, the first portrait of Shakespeare engraved in America.

In 1788 was printed in Philadelphia the first American Shakespearean book, *A Philosophical Analysis . . . of some of Shakespeare's Remarkable Characters*, by Prof. William Richardson of Glasgow University, at that time in high repute as a Shakespearean critic.

But it was not until the last decade of the 18th Century that the myriad minded Shakespeare came into really formative contact with the virile and versatile American mind.

Joseph Hopkinson was then a young lawyer in Philadelphia. He was a member of the American Philosophical Society, and later its Vice President. His father had signed the Declaration of Independence. He himself was soon to attain celebrity as the author of Hail Columbia, and still later to find eminence in Congress and as a Federal Judge. With a coterie of his literary friends who were conscious of the oncoming growth of the American people he wished to see our new nation cultivate science and letters as well as politics and theology. He foresaw, so he said, America as "the nurse and patron of the arts."

The Philadelphia publishers, Bioren and Madan, printed in 1795 in eight little volumes the *Plays and Poems of William Shakespeare*. Joseph Hopkinson, then 25 years old, promoted this enterprise and for it wrote the Preface, and the Life of Shakespeare. The words "First American Edition" were prominently displayed on the title page of the volumes. They were sold not only in Philadelphia, but in New York and in the Southern cities of our country. This Preface is the first Shakespearean Essay of American authorship. One must read it to feel how conscious was the writer that he was a missionary introducing to our virgin soil a new and wonderful cult.

Seven years later (1802) our friends in Boston produced the "First Boston Edition" chiefly for New England consumption. By a slip of the pen one volume is entitled "First American Edition"—but pass that. In these two sets of books the whole world of Shakespeare first swam into the ken of our forefathers.

Keeping step was the Stage. Hallam's American Company, housed in Southwark, and a little later Thomas Wignell's Company at the fine new theater in Philadelphia, were giving more frequent and much more competent presentations of the plays of Shakespeare as well as of other current plays

of the London stage. They went on the road to other leading cities and America became Shakespeare conscious.

Thus was created in this country just at the beginning of the last century a large number of readers who read Shakespeare and a crowd of playgoers who saw his plays.

The consciousness of the influence of a master mind came rapidly. The demand for his printed works and for the presentation of his plays was insistent. New edition quickly followed new edition. To print an edition of Shakespeare's works was a considerable task for the early American printer. As a substitute we find at this time many printings in a single volume of Dodd's *Beauties of Shakespeare*. They are cheap little books, set up by the compositor of the country newspaper at intervals when he had nothing else to do, and printed in little towns of which one rarely hears. It is surprising how many of these volumes appeared here over a hundred years ago. This is the best witness I know for the universality of the demand of the people for some knowledge of Shakespeare's poetry.

But the more serious study of the plays soon began.

By the beginning of the 19th Century the editing, annotating and publishing of the Works of Shakespeare in London had become a great affair. Curiosity to explore this growing field of literature quickly arose here. A literary periodical called *The Portfolio* had been started in Philadelphia in the year 1800 by Joseph Dennie, a young friend of President John Adams and a genuine man of letters. He and his friends were ambitious to spread both the fame and the study of Shakespeare, and many Shakespearean articles appeared in *The Portfolio*. In 1804 Dennie persuaded Philadelphia printers to undertake to reprint in seventeen volumes the latest London edition of Shakespeare "with the notes of the various commentators," a really formidable undertaking.

This *First American Variorum* took five years to complete. Dennie himself contributed some notes "by the American editor," and this notable set of books stood proudly on the shelves of our grandfathers, witnessing what Philadelphia could do to furnish the new world with polite literature.

From this time on American printing presses have poured forth an unending stream of editions of the Works of William Shakespeare, many of them edited by scholars and carefully and worthily printed, still more of them cheaply reprinted, but witnessing that it is not only the wealthy or the erudite who wish to possess the works of our great dramatist, but the people who cannot buy fine books. These have saved their pennies in order that on the shelf in the little home on the advancing frontier they might have alongside of their Bible a set of the Works of Shakespeare.

Coincident with this more general dissemination of the printed page of Shakespeare there was trained up a generation of theater goers knowing the stage tradition and keenly appreciating the power of these great plays and how they should be performed. They were not literati, they were mostly gallery gods; but when George Frederick Cooke, and a little later Edmund Kean, then William Macready, and then Fanny Kemble came from the stages of Drury Lane and Covent Garden and gave the plays of Shakespeare in the Walnut Street Theatre in this city, they turned out in force and evidenced that sort of appreciation of how the plays ought to be presented which, as these actors tell in their memoirs, stimulated them to their best work, for there can be no great acting without the trained and appreciative audience.

The old American Company had numbered several competent players well known here in Philadelphia, but there had appeared no really great American actor until one grew up in our midst under just these influences, Edwin Forrest. This handsome, virile, muscular Philadelphian made a deep impress on the dramatic future of America. He was not a subtle actor. He could not play Hamlet as did his greater successor Edwin Booth; but as Othello, and King Lear and in other parts which show our suffering humanity under the influence of titanic passion he was unsurpassed. In every city he had a following who crowned him king of tragedy. Declamation, now an almost forgotten art, is none the less a

powerful force by which mighty thoughts may be forced into thick heads who would otherwise receive no impression at all.

In the first half of the 19th Century not only were Philadelphia publishers active in disseminating the printed page of the plays, and the Philadelphia stages in carrying on the great stage tradition, but the University of Pennsylvania was inculcating a love of English literature including courses on the Shakespearean drama. Many other colleges had been slow to do this. The Puritan, the Presbyterian, the Methodist, and the Quaker discouraged the study of dramatics in any language except in the original Greek. At the University of Pennsylvania—while the last century was yet young—Professor Henry Reed overcame this obstacle by using Shakespeare's historical plays as an illuminating medium for the teaching of English history in lectures which have had wide influence and have been printed again and again. This emphasis on the teaching value of the Shakespearean Drama has continued at the University to our own day, and has had its full and lasting fruition in the labors of Dr. Schelling.

Thus more than a hundred years ago Shakespeare came to his own in the United States. The great romantic movement in English literature had found its reflex here and had immensely helped to promote the romantic drama. Everywhere there was springing up the feeling that the plays of Shakespeare were so great that it is not enough merely to see them on the stage and to read them, but that if carefully studied they will yield strange secrets and disclose depths of human nature not elsewhere sounded.

In 1852 a small band of Philadelphia lawyers agreed to meet together in the evenings for the special study of these plays. This Society has continued in unbroken succession until today, but its chief pride is the part which it had in introducing Dr. Horace Howard Furness to his life work. He had joined the Society as a young man, in 1860, and as its secretary wrote notes of its proceedings which he soon developed into a form for publication. Ten years later he was led to undertake the truly great and monumental work with

which his fame must always be connected and which throughout the world has brought renown upon himself and our city. He was a scholar in the broader, not in the narrower sense. His scholarship was shot through with humanity, benevolence and humor. There had been no *Variorum Edition of Shakespeare* published since the one known as *Boswell's Malone*, issued in 1821. There was a great mass of undigested and inaccessible Shakespearean thought and commentary which needed to be sifted and made useful through the preparation of another and larger variorum edition, and so was born the *New Variorum Shakespeare*. The first volume containing Romeo and Juliet appeared in 1871. It disclosed an extent of textual collation such as had not before been attempted, accomplished with precision, sanity, and good judgment. It showed skill in absorbing, condensing and rendering not only readable but delightful the unwieldy mass of Shakespearean exegesis and criticism with which the various editions and books were filled.

Up to this time the study of Shakespeare had shown an unfortunate tendency to engender bitter controversy. The *odium Shakespeareanum* threatened to rival the *odium theologicum*. Dr. Furness changed all that. There was never a bitter word. His opponents were met by kindly humor rather than by ridicule, and the way cleared for the friendly rather than the acrimonious settlement of points of difference.

The task thus undertaken was too vast for any one man. Fourteen volumes appeared, the result of forty odd years of incessant labor and then he laid it down to be taken up by his son Horace Howard Furness, Jr., who carried the work on through five more plays until in the midst of his career he too was cut down. Nineteen out of the thirty-six plays were thus given to the world, furnished with an apparatus for scholarly investigation such as is nowhere else to be found; and wherever Shakespeare is appreciated (and where is he not?), these books will be found in the library of whoever is to undertake any serious study of the works of Shakespeare.

But the task is unfinished. Throughout the world there

is audible demand that it should be finished. The American Philosophical Society has already made a most generous contribution to help this accomplishment, and our hopes are now high that it will be completed.

Thus much has Philadelphia done to advance the knowledge and appreciation of the Works of William Shakespeare both in this country and abroad. In fact it has done much more for time has permitted mention of only a few outstanding names and only some of their labors. Nothing has been said as to the 20th Century, which has seen a most extraordinary progression of Shakespearean study into old and new fields. The attack upon what is foolishly called the Shakespeare Idolatry, while pricking some bubbles, has only placed his fame on a more sure foundation.

This continually expanding influence of Shakespeare is due to the increasing fascination exercised by a mind that saw so many things, could use so many different words, peered so far into old and new problems, created living men, women, fairies and devils; who illuminated the whole field of letters by touching it with the magic of his fancy and the glory of his phrase until his works, if achievement in literature is to be judged by the extent to which mind influences mind, must be ranked facile princeps.

Truly there would seem to be no limit to the fitness of the stories embodied in these plays "to reach to all persons, serve for all time, teach the living and revive the dead." You see I am repeating the words of Sir Thomas North with which I started. In truth, it is better to see learning in noble men's lives—Hamlet, Lear, Othello—I need not name them—than to read it in philosophers' writings. The enormous flood of imaginative fiction of our day proves this even though the art is not as finely practiced as it was by the Elizabethans. We may with confidence repeat Dr. Samuel Johnson's words: "The stream of time, which is continually washing the dissoluble fabrics of other poets, passes without injury by the adamant of Shakespeare."

But we must take note of two changes which are in progress.

There is no longer the large popular audience trained to enjoy the music of the verse of Shakespeare's plays. The modern realistic conversational stage, and still more the moving picture, has deadened the taste of the theater going public for the poetical drama. In consequence few actors can now adequately articulate or properly recite Shakespearean verse; and there is no longer that extensive contact of the people with his plays on the stage which our fathers knew. This misfortune may carry its own cure. When people are thoroughly satiated by the "thrills" of the movies they may turn again to the charm of the Romantic Drama.

The other change is still more significant. For centuries academic learning centered around the Latin and Greek classics. Before our very eyes have these been dethroned, and our colleges now carry on great fields of instruction from which the old classics are excluded. But no useful study, whether in science or the humanities, can grow without roots founded in letters. Otherwise it is dumb. Consequently in place of the old classics has been set up the study of Shakespeare and other English classics.

Now this has both its glories and its dangers. Anything thus classicized tends to become systematized, and if over-systematized may become crystallized, mummified. I for one do not believe this can happen to the Works of Shakespeare. We must not now study merely by rule him who broke all the rules of the Drama. His mind was too virile, his spirit too free, his message too modern, his appeal too universal to permit this. The best antidote for this that I know is the *New Variorum Shakespeare*, enlightened by fine scholarship, and based not upon mere microscopic examination, but upon the broadest human interest, causing the plays to hold the mirror up to nature, so as to show virtue her own feature and scorn her own image.

And so let me follow the prophecy of Dr. Johnson with another Shakespearean prophecy and thus conclude.

When the Revolutionary War had come to an end and commissioners from Great Britain and her former Colonies

met to sign a treaty of peace, the secretary of the British commission was a highly cultivated little Welshman, with an acute mind and a smile playing around the corners of his lips. His name was Maurice Morgann, and he was a lifelong lover and student of Shakespeare. I like to think of him in friendly converse with Benjamin Franklin over the future of the new country of which the treaty was to fix the boundaries. Possibly Maurice Morgann had some influence upon the terms of the treaty, but his chief title to fame is not that. He wrote a book. It was a jeu d'esprit written in bravado ostensibly to prove the paradox that Sir John Falstaff is not a coward, but really to show the magic power of William Shakespeare to create men and women whom we can know as our old friends; not types, but men. It is the first of one thousand essays which have pursued this theme.

In this book, incensed at the disparagement of Shakespeare as a rude Barbarian by Voltaire, Morgann predicts—

"When the hand of time shall have brushed off his present Editors and Commentators, and when the very name of Voltaire, and even the memory of the language in which he has written, shall be no more, the Appalachian Mountains, the banks of the Ohio, and the plains of Sciota shall resound with the accents of this Barbarian: In his native tongue he shall roll the genuine passions of nature; nor shall the griefs of Lear be alleviated, not the charms and wit of Rosalind be abated by time" (p. 65).

This was printed in London in 1777, six years before the treaty of Paris gave to our nation the banks of the Ohio and the plains of Sciota. It looks a long way ahead. It bids fair to come true.

PHILADELPHIA.

WHERE IS FRANKLIN'S FIRST CHART OF THE GULF STREAM?

FRANKLIN BACHE

(Read April 24, 1936)

Prefatory Note

In 1769 or 1770 Doctor Franklin procured the engraving of the first chart of the Gulf Stream, but extensive inquiries in America and England have failed to find an example. We should have one in America and it is hoped that the circulation of this paper may bring one to light. Franklin not only procured the engraving of the first chart but to America, through him, belongs the credit of making and publishing the first scientific observations of the Stream and of pointing out its several values to navigation.

Mr. H. A. Marmer of the United States Coast and Geodetic Survey published in the *Geographical Review*, July, 1929, "The Gulf Stream and its Problems." This was reprinted in the Smithsonian Report for 1929, pages 285–307, and in pamphlet form in 1930 at the U. S. Government Printing Office. It is a fine example of condensed, accurate and thoroughly documented scientific information so well done as to be of equal interest to scientists and laymen. The references given by Mr. Marmer are placed at the end of this paper.

Quotations from Mr. Marmer and Doctor Franklin are printed from a font differing from that of the other text.

Albert Henry Smyth's ten volume *The Life and Writings of Benjamin Franklin* has been used for the quotations from Doctor Franklin.

There is appropriate and excellent authority for the extensive use of Franklin's and Mr. Marmer's writings. The Doctor in his *Autobiography* tells that a young preacher came to Philadelphia, who delivered excellent discourses and was greatly admired until it was found that most of his sermons had been delivered in England by the famous Doctor James Foster. Franklin says, referring to the young preacher after his discomforture:

> "I stuck by him, however, as I rather approv'd his giving us good sermons compos'd by others, than bad ones of his own manufacture, tho' the latter was the practice of our common teachers."

Finally, I wish to express my gratitude to Colonel Lawrence Martin, Chief, Division of Maps of the Library of Congress, who encouraged me and went to great trouble to furnish me information. Without him the paper would not have been written.

Abstract

Doctor Franklin, Deputy Postmaster-General of the Colonies, in 1769, was in England and there heard complaints from America that westbound mail packets took two weeks longer in crossing than did American merchant ships.

A Captain Folger, a Nantucket whaler, being in London, Franklin inquired of him and received the suggestion that the delay was due to the English packets breasting the Gulf Stream, which they continued to do notwithstanding that the American whaling

captains told them of it and advised them how to avoid it, but the English captains "were too wise to be counseled by simple American fishermen."

Franklin thereupon procured the engraving of the first chart of the Stream. No example of this chart can be found in any of the great collections. It is hoped one may be brought to light.

Franklin, while in his seventies, in the course of three North Atlantic crossings, took observations of the water temperature as the ship entered and left the Gulf Stream, with the idea that navigators by doing the same could be warned of the approach to the American Coast, and could use or avoid the Stream, according to the direction in which they were going.

He stated his theory of the cause of the Stream which after 160 years of observation is accepted.

Thus an American had the first chart of the Stream engraved, made the first scientific observations of it and was the first to ascribe correctly its cause.

THE FIRST record of the Gulf Stream was on April 22, 1513, when, as related in the Chronicle, of Ponce de Leon's Expedition, which resulted in the discovery of Florida, it had encountered:

> A current such that, although they had great wind, they could not proceed forward, but backward and it seemed that they were proceeding well; and at the end it was known that in such wise the current was more powerful than the wind.[1]

Thus the Gulf Stream was first noticed.

Apparently the Spaniards soon learned that this northerly flowing current was not merely a local current but one of wide extent; for six years later when Antonio de Alaminos set out for Spain from Vera Cruz, he sailed northward with the Gulf Stream for a number of days before turning east toward Europe. This same Alaminos was pilot of Ponce de Leon's expedition of 1513, when the Gulf Stream was first noted. It is, therefore, quite proper to credit the discovery of the Gulf Stream to Alaminos.[2]

For two and a half centuries following its discovery the growth of knowledge regarding the Gulf Stream was slow. The story is told in detail by Kohl [3] and more briefly by Pillsbury. During this period, to be sure, the mariner and more especially the whaler, became acquainted with the

[1] L. D. Scisco. "The Track of Ponce de Leon in 1513," *Bull. Amer. Geogr. Soc.*, **45**, pp. 721–735, 1913; reference on page 725.

[2] H. A. Marmer: *The Gulf Stream and its Problems.*

[3] J. G. Kohl: *Geschichte des Golfstroms und seiner Erforschung von den ältesten Zeiten bis auf den grossen Amerikanischen Bürgerkrieg*, pp. 1–114, Bremen, 1868.

> Gulf Stream throughout the greater part of its course. Much of this information, however, was kept as a professional secret, . . .[4]

The recorded interest of Doctor Franklin in the Gulf Stream continued over about sixteen years, from 1769 to 1785.

Franklin's grandnephew, Jonathan Williams, Jr., in August and September, 1785, was a fellow passenger with him on Franklin's last voyage from Europe to America and under his direction made the experiments on water temperatures. Williams had rendered useful services to America during the Revolution as Commercial Agent at Nantes and later became the first Superintendent of the U. S. Military Academy. In 1799 Williams published his *Thermometrical Navigation* giving a series of additional and later observations by himself. The first systematic observations were begun in 1845 by the U. S. Coast Survey under the superintendency of Alexander Dallas Bache and were thereafter continued at intervals.

Magnitude of the Stream

Matthew Fontaine Maury in his *The Physical Geography of the Sea*, page 23, New York, 1855, says:

> There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottoms are of cold water, while its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in the world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon.

Mr. Marmer states that the latest and most comprehensive investigation of the Gulf Stream was carried out between the years 1885 and 1889 by Lieut. (later Rear Admiral) J. E. Pillsbury, U. S. Navy, while attached to the Coast and Geodetic Survey, who described the Stream as

[4] H. A. Marmer: *The Gulf Stream and its Problems.*

> . . . the grandest and most mighty . . . terrestrial phenomenon.[5]

That the above characterizations are justified is borne out by Mr. Marmer who says that in the Straits of Florida, east of Cape Florida, the Stream is 42 geographical miles wide, with an average depth of approximately one-third of a mile, and that while the current near the surface is approximately $3\frac{1}{2}$ nautical miles per hour, the velocity decreases with depth so that the average can be taken as one nautical mile per hour. That, therefore, each hour it carries 14 cubic miles or 100 billion tons of water past Cape Florida into the sea. This being nearly 500 times the extreme flood discharge of the Mississippi.

Mr. Marmer brings out that contrary to popular belief, the Gulf Stream is not a river in the sea of comparatively uniform temperature throughout but that often as far south as the Straits of Florida, the temperature of the water decreases from 80 degrees at the surface to 45 degrees at a depth of three or four hundred fathoms, and that the velocity of the surface of the Stream decreases from a maximum of three and one-half knots in the Straits of Florida to less than one knot north of Cape Hatteras. He notes the sharp separation between the west margin of the Stream and the adjoining ocean waters, known as the Cold Wall and strikingly instances:

> An occasion in 1922 when the U. S. Coast Guard Cutter, "Tampa," which is about 240 feet long, was placed directly across the Cold Wall and the temperature of the sea at the bow was found to be 34 degrees, while at the stern it was 56 degrees.[6]

Franklin's Interest in the Stream

In 1769 during the period when Franklin was Deputy Postmaster General of the Colonies, he was on October 29th,

[5] J. E. Pillsbury—The Gulf Stream: Methods of the Investigation, and Results of the Research, Appendix No. 10 of Rep. of the Supt. of the Coast and Geodetic Survey for 1890, pp. 459–620, Washington, D. C., 1891; reference on p. 472.

[6] R. DeC. Ward: "A Cruise with the International Ice Patrol," *Geogr. Rev.*, 14, pp. 50–61, 1924; reference on p. 54.

in London and wrote a letter to his friend, Anthony Todd, then Secretary of the British General Post Office, acquainting him with a complaint made by Board of Customs, at Boston, to the Lords of the Treasury in London to the effect that packets between Falmouth and New York were generally a fortnight longer in their passages than merchant ships from London to Rhode Island, and saying that he had received pertinent information from a Captain Folger, a very intelligent Mariner of the Island of Nantucket.

Colonel Lawrence Martin, Chief of the Division of Maps, of the Library of Congress, has probably identified Captain Folger as being Timothy Folger, and says that the source of his information is Mr. Clarke E. Congdon, President of the Nantucket Historical Association, who in turn cites Starbuck's *History of Nantucket*.

Franklin, in his *Maritime Observations* made in his letter to David Le Roy, written at sea in August, 1785, relates the matter—

> Vessels are sometimes retarded, and sometimes forwarded in their voyages, by currents at sea, which are often not perceived. About the year 1769 or 1770, there was an application made by the Board of Customs, at Boston, to the Lords of the Treasury in London, complaining that the packets between Falmouth and New York were generally a fortnight longer in their passages, than merchant ships from London to Rhode Island, and proposing that for the future they should be ordered to Rhode Island instead of New York. Being then concerned in the management of the American Post Office, I happened to be consulted on the occasion; and it appearing strange to me, that there should be such a difference between two places, scarce a day's run asunder, especially when the merchant ships are generally deeper laden, and more weakly manned than the packets, and had from London the whole length of the river and channel to run before they left the land of England, while the packets had only to go from Falmouth, I could not but think the fact misunderstood or misrepresented. There happened then to be in London, a Nantucket sea captain of my acquaintance, to whom I communicated the affair. He told me he believed the fact might be true;

> but the difference was owing to this, that the Rhode Island captains were acquainted with the Gulf Stream, which those of the English packets were not. "We are well acquainted with that stream," says he "because in our pursuit of whales, which keep near the sides of it, but are not to be met within it, we run down along the sides and frequently cross it to change our side; and in crossing it have some times met and talked with those packets, who were in the middle of it and stemming it. We have informed them that they were stemming a current, that was against them to the value of three miles an hour; and advised them to cross it and get out of it; but they were too wise to be counselled by simple American fishermen. When the winds are but light," he added, "they are carried back by the current more than they are forwarded by the wind; and if the wind be good, the subtraction of seventy miles a day from their course is of some importance." I then observed it was a pity no notice was taken of this current upon the charts, and requested him to mark it out for me, which he readily complied with, adding directions for avoiding it in sailing from Europe to North America. I procured it to be engraved by order from the general post-office, on the old chart of the Atlantic, at Mount and Page's, Tower Hill; and copies were sent down to Falmouth for the captains of the packets, who slighted it however; but it is since printed in France, of which edition I hereto annex a copy."

We here have reference to the first two charts of the Gulf Stream, both of American inception, and published through Franklin, the first in England, the second in France.

He continues and enunciates his theory of the cause of the Stream:

> This Stream is probably generated by the great accumulation of water on the eastern coast of America between the tropics, by the Trade Winds which constantly blow there. It is known that a large piece of water ten miles broad and generally only three feet deep, has by a strong wind had its waters driven to one side and sustained so as to become six feet deep, while the windward side was laid dry.

And again:

> The power of the wind to raise water above its common level in the sea is known to us in America, by the high tides occasioned in all our seaports when a strong northeaster blows against the Gulf Stream.

There Franklin states the, now accepted, theory of the cause of the Gulf Stream.

Quoting Mr. Marmer:

> A century and a half ago, Franklin thought that the Gulf Stream "... is probably generated by a great accumulation of waters on the eastern coast of America between the tropics by the trade winds which constantly blow there."
>
> And in the trade winds which bring about a westerly flow of the waters in the equatorial regions of the Atlantic Ocean, is still found the primary cause of the Gulf Stream. . . .

The importance of devising a method by which navigators might know positively when they entered or left the Gulf Stream doubtless occurred to Franklin after he had published the first chart and accordingly he directed his attention during his next three North American crossings to his temperature observations.

He made the first of his three series of water temperature observations during his voyage from England in 1775. While he was on the Atlantic the battle of Concord and Lexington was fought. On his arrival in Philadelphia he wrote to his old friend, Dr. Priestley, 16 May, 1775.

> You will have heard, before this reaches you, of a march stolen by the Regulars into the country by night, and of their *expedition* back again. They retreated twenty miles in six hours. . . .
>
> In coming over, I made a valuable philosophical discovery, which I shall communicate to you when I get a little time.

The "philosophical discovery" undoubtedly refers to his observations on changes of temperature of ocean water, that

> the thermometer may be a useful instrument to a navigator, since currents coming from the northward into southern

> seas will probably be found colder than the waters of those seas, as the currents from southern seas into northern are found warmer. And it is not to be wondered, that so vast a body of deep, warm water, several leagues wide, coming from between the tropics and issuing out of the Gulf into the northern seas, should retain its warmth longer than the twenty or thirty days required to its passing the banks of Newfoundland. The quantity is too great, and it is too deep to be suddenly cooled by passing under a cooler air.

This is the first suggestion that observations of changes of water temperatures might be an aid to navigation.

Franklin's Qualifications as a Maritime Observer

In the eighteenth century the towns of the American colonies were almost all on tide water. Inland transporation was slow and expensive, consequently the ships docked as near the place of production of their prospective cargoes as possible. Almost any place affording fifteen feet of water at high tide could become a loading place for the light draft ships of the day. We were ocean-minded. Franklin, on his first trip from Boston to Philadelphia was three days by sloop from Boston to New York. Then thirty hours by boat to Amboy and by row boat from Burlington to Philadelphia. In the following year he returned to Boston by sea in two weeks. In the same year he made his first trans-Atlantic crossing.

He was an expert swimmer and while in England attracted attention by swimming the two or three miles from Chelsea to Blackfriars.

Franklin while crossing the North Atlantic eight times and in shorter coastal voyages spent about two years of his life on the Atlantic. A passenger in making one two months' Atlantic crossing in a sailing vessel of the eighteenth century learned more about the ocean and its navigation than a seafarer today would learn in ten crossings in modern liners.

During the Revolution the American Navy consisted chiefly of privateers, operating in the eastern Atlantic. Franklin according to Francis Wharton in his *Diplomatic Correspondence of the American Revolution*—

> In addition to these diplomatic and financial functions, which put him in the position of a Secretary of State and a Secretary of the Treasury, he had to exercise the functions of a Secretary of War in the selection and forwarding of supplies, of a Secretary of the Navy in supervising the fitting out and regulation of privateers numerous enough to scour all the European waters, and of a Supreme Admiralty Judge in determining prize questions in which these privateers were concerned, and in adjusting the almost innumerable controversies in which those concerned in these privateeres were engaged. . . .
>
> The functions thus exercised by Franklin were of the same general character as those which in England are exercised by the Chancellor of the Exchequer, the Secretaries for Foreign Affairs, the Admiralty Board, the War Secretaries, and the Courts of Admiralty.

Little escaped Franklin's observation. The cause and cure of smoky chimneys and the similarity between artificially generated electric current and lightning filled in his time between his printing, writing, politics and money making. With his seafaring experience and his ever busy mind it was impossible that the Gulf Stream should escape his attention. His letter to David Le Roy, published as his "Maritime Observations," is witness to his interest in the sea.

He disarmed professional sailors, some of whom he said:

> . . . have a little repugnance to the advice of landmen, whom they esteem ignorant and incapable of giving any worthwhile advice; though it is certain that most of their instruments were the invention of landmen. At least the first vessel ever made to go on the water was certainly such.

The quality of his mind and his experience when he made his first recorded observations 1775 at the age of 69 well equipped him to design his experiments and ten years later when he was 79 and was making his last voyage and directed his grandnephew, Jonathan Williams, Jr., in the last of his three series of observations, he had the additional experience of two ocean crossings.

I have been unable to locate a single copy of the Mount and Page chart. We should, if possible, get a copy of it and have it in this country.

The second chart, namely the one which Franklin had printed in France, is reproduced here. The third chart also reproduced here is that which accompanies the American Philosophical Society publication of Franklin's letter to David Le Roy. It was engraved by James Poupard. In the upper left hand corner there is an insert chart showing most of the north Atlantic Ocean with what at first glance appears to be a number of broken lines suggestive of an ocean current. As a matter of fact the insert has nothing to do with the Gulf Stream or Franklin's letter about it, but was intended to illustrate an article read before the Society by John Gilpin, on his theory of the annual migration of herring, and was put on the same plate to save some cost of engraving. This chart follows the French one so far as the course of the Stream is concerned. The engraver, M. Poupard, added an amusing cartouche showing Neptune as a merman, immersed to his waist in the ocean, wearing a crown and gesticulating with his trident at Doctor Franklin, who stands on the shore both seemingly in lively conversation, perhaps exchanging information about the Gulf Stream.

Franklin does not refer to this conversation in any of his writings and until some learned society acquires the writings of Neptune it will not be known exactly what was said.

The combination of the herring migration map and the Gulf Stream chart on the same plate illustrates the thriftiness in those days of the Philosophical Society, as do their Minutes which reveal that the Society disputed the bill of M. Poupard and succeeded in getting him to reduce his charge for the plate. But this economy had the result of causing nearly all editors of Franklin's *Works* to place the route of the herring on the principal map, instead of as an insert in one corner, so that Franklin is made apparently responsible for preparing a map showing not only the course of the Gulf Stream, as he did show it, on his French chart, but in addition what appears to be a vague and unexplained roughly circular north Atlantic current which we now know not to be a current at all but Mr. Gilpin's herring. In fact, very close examination

shows that the individual dashes in the broken lines of the herring migration are in the shape of minute fish.

The latest example of this hybrid appears in Albert Henry Smyth's *The Life and Writings of Benjamin Franklin* and is reproduced here. Franklin says in his letter to Le Roy that it was accompanied by a copy of the French chart and Mr. Smyth so refers to the chart he publishes but it very obviously and certainly is not. Mr. Gilpin's paper on the migration of herring did not appear until several years after the engraving of Franklin's French chart and not for fifteen years after the engraving of the chart of Mount and Page's, which, therefore, when found, will show the same absence of herring as in the French chart. It is to be hoped that any future publication of Franklin's *Maritime Observations* will reproduce the French chart he refers to in his Le Roy letter.

I have been unable to find any precedent for the word "Minutes" for a unit of velocity as it, apparently is used on the maps. The rate of flow of the stream is shown on the French chart as being "3½ minutes," "3 minutes" etc. A not entirely satisfactory explanation is that a minute of the earth's circumference corresponds to a nautical mile and that a knot is the unit of velocity at sea and represents one nautical mile per hour and it may be surmised that three "minutes" on the chart is the equivalent of three knots.

Franklin's observations on the Gulf Stream very possibly appeared to him as of greater practical importance than his electrical experiments. Steam navigation, together with the multiplication of light houses, light ships, buoys, and other modern aids to navigation have made the utility of a method to ascertain the exact location of the western, Cold-Wall, side of the Gulf Stream of much less importance than in Franklin's time but when he made the observations their practical value was probably greater than that of his electrical experiments.

It is interesting to note in both cases how quickly he moved from observation and experiment to practical application: in one case to the lightning rod, in the other to the determination by ship captains of their approach to our eastern coast by the use of the thermometer in the ocean water.

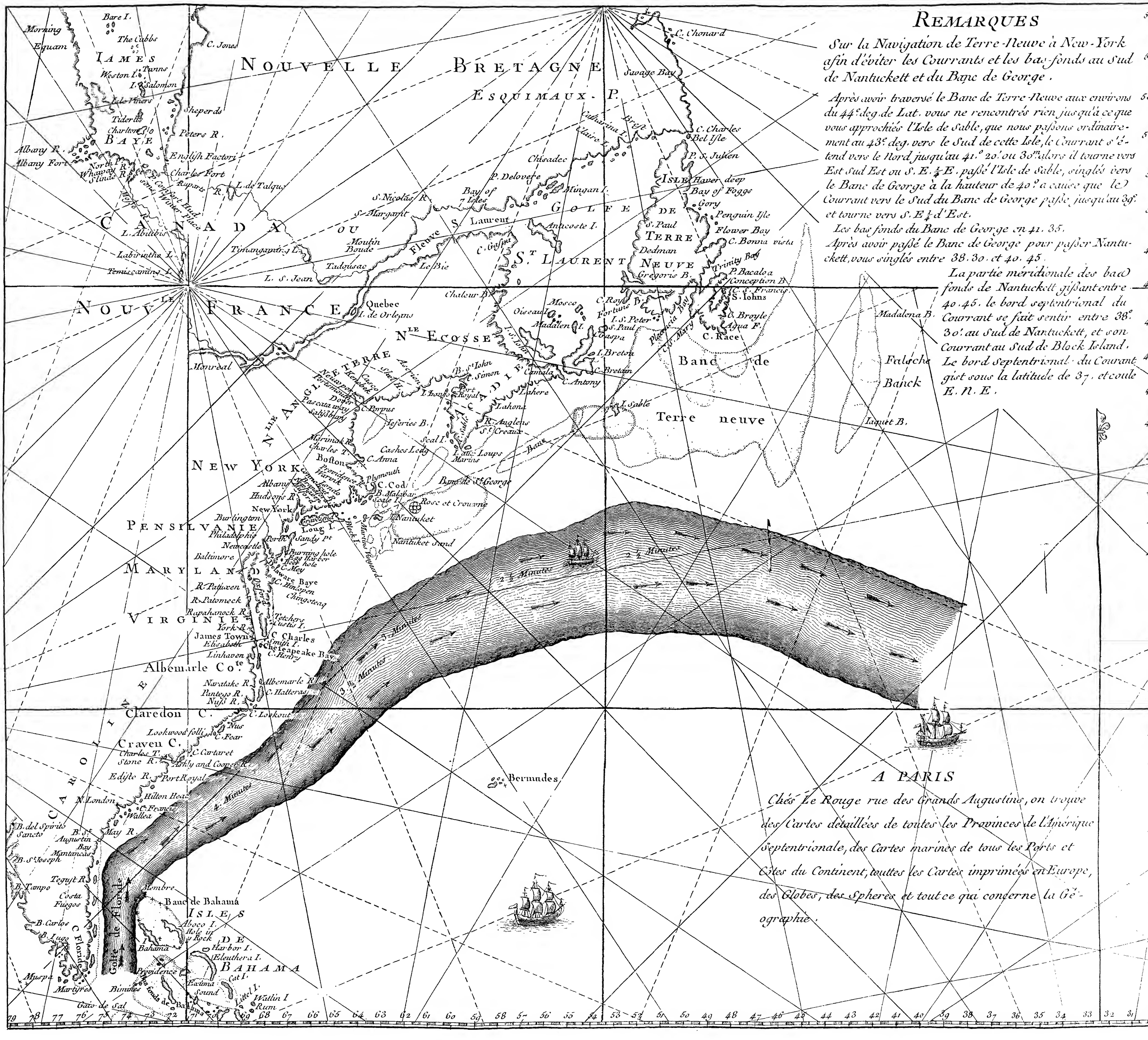
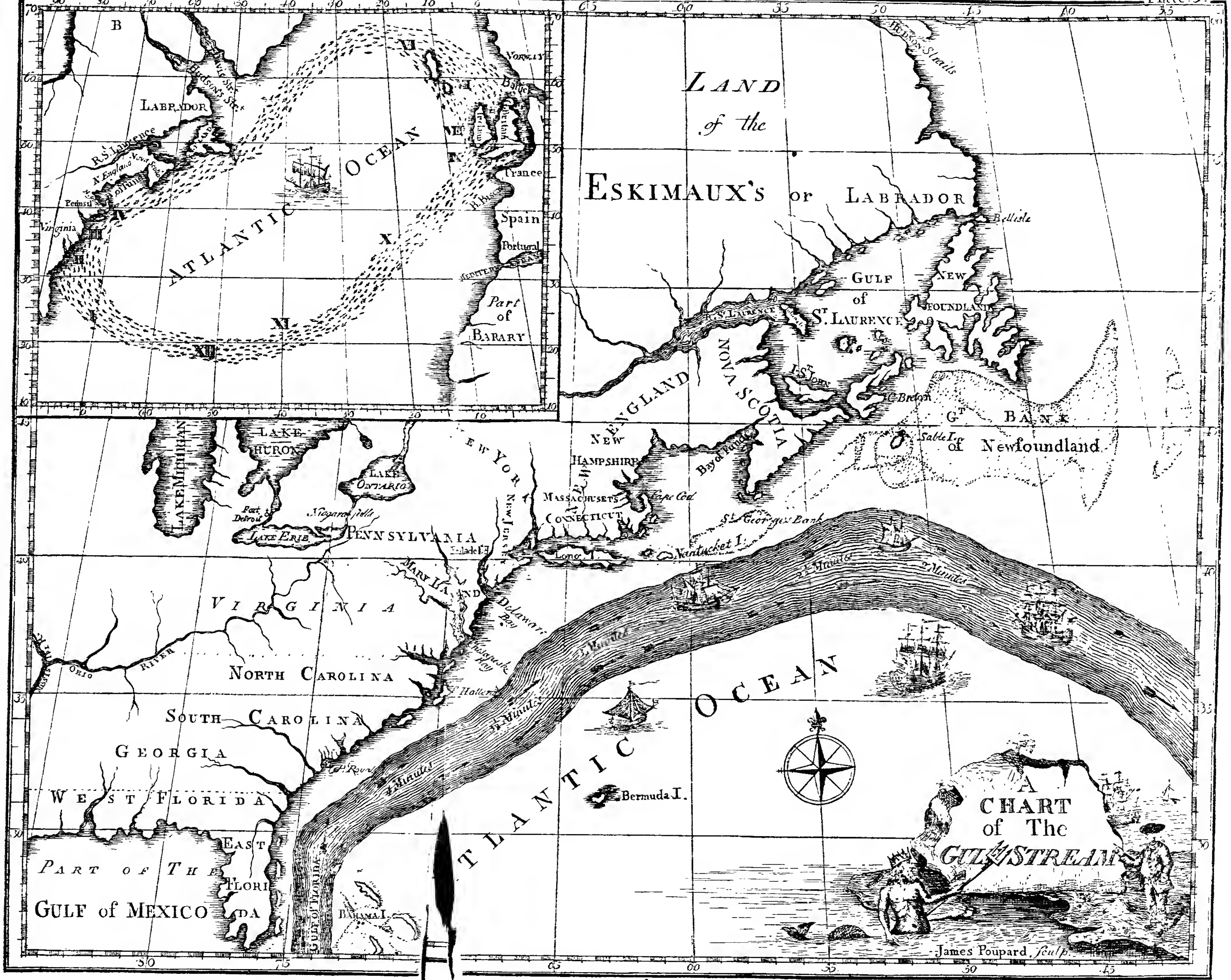
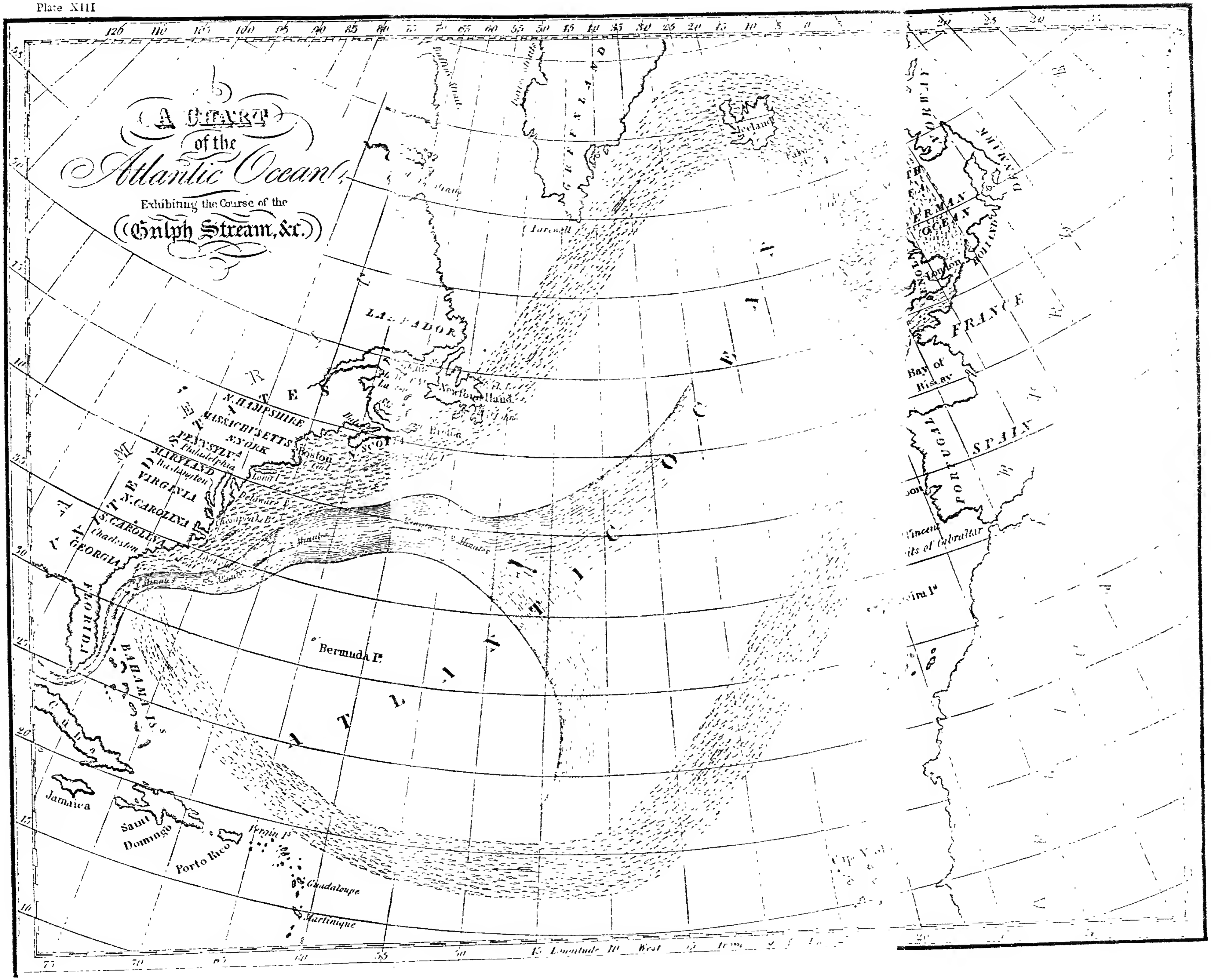

REMARQUES
Sur la Navigation de Terre-Neuve à New-York afin d'éviter les Courrants et les bas-fonds au Sud de Nantuckett et du Banc de George.
Après avoir traversé le Banc de Terre-Neuve aux environs du 44e deg. de Lat. vous ne rencontrés rien jusqu'à ce que vous approchiés l'Isle de Sable, que nous passons ordinairement au 43e deg. vers le Sud de cette Isle, le Courrant s'étend vers le Nord jusqu'au 41.° 20.' ou 30m. alors il tourne vers Est Sud Est ou S. E. ¼ E. passé l'Isle de Sable, singlés vers le Banc de George à la hauteur de 40.° a cause que le Courrant vers le Sud du Banc de George passe jusqu'au 39e. et tourne vers S. E ¼ d'Est.
Les bas fonds du Banc de George en 41. 35.
Après avoir passé le Banc de George pour passer Nantuckett, vous singlés entre 38. 30. et 40. 45.
La partie méridionale des bas fonds de Nantuckett gissant entre 40. 45. le bord septentrional du Courrant se fait sentir entre 38.° 30.' au Sud de Nantuckett, et son Courrant au Sud de Block Island. Le bord Septentrional du Courrant gist sous la latitude de 37. et coule E. N. E.
A PARIS
Chés Le Rouge rue des Grands Augustins, on trouve des Cartes détaillées de toutes les Provinces de l'Amérique Septentrionale, des Cartes marines de tous les Ports et Côtes du Continent, touttes les Cartes imprimées en Europe, des Globes, des Spheres et tout ce qui conserne la Géographie.
NOUVELLE BRETAGNE
ESQUIMAUX. P.
JAMES BAYE
CANADA OU NOUVELLE FRANCE
GOLFE DE ST. LAURENT
ISLE DE TERRE NEUVE
Nle ECOSSE
Nle ANGLETERRE
ACADIE
NEW YORK
PENSILVANIE
MARYLAND
VIRGINIE
CAROLINE
ISLES DE BAHAMA
Fleuve S. Laurent
Quebec
Monreal
Boston
New York
Philadelphia
C. Cod
Nantuket
Banc de Terre neuve
Falsche Banck
Banc de S. George
Bermudes
Golfe de la Floride
C. Florida
C. Hatteras
C. Lookout
C. Fear
C. Charles
Chesapeake Bay
James Town
Albemarle Co.te
Claredon C.
Craven C.
Baltimore
Burlington
Albany
I. Sable
C. Breton
C. Race
S. Iohns
Conception B.
Trinity Bay
Placentia Bay
Madalena B.
Iaquet B.
3 Minutes
3 ½ Minutes
4 Minutes
2 ½ Minutes

Plate 5.



facing page 315.

Plate XIII



A Chart of the Atlantic Ocean Exhibiting the Course of the Gulph Stream, &c.
GREENLAND
Iceland
LABRADOR
Newfoundland
N. HAMPSHIRE
MASSACHUSETTS
N. YORK
PENNSYLVA
Philadelphia
MARYLAND
VIRGINIA
N. CAROLINA
S. CAROLINA
Charleston
GEORGIA
FLORIDA
Boston
BAHAMA IS.
CUBA
Jamaica
Saint Domingo
Porto Rico
Guadaloupe
Martinique
Bermuda Is.
ATLANTIC OCEAN
FRANCE
SPAIN
PORTUGAL
Bay of Biscay
London
HOLLAND
GERMAN OCEAN
NORWAY
Strait of Gibraltar

REPORTS OF PROGRESS ON PROJECTS SPONSORED BY THE AMERICAN PHILOSOPHICAL SOCIETY *

THE HISTOLOGICAL BACKGROUND FOR DWARFISM IN ZEA MAYS

LUCY B. ABBE

Eighteen cultures segregating for dwarf or dwarf-like types of Zea mays were grown in the Plant Breeding plot at Cornell University last summer (1935). Nine different dwarf types were represented in these cultures. Further dwarf types and their normal sibs were kindly provided by Dr. Emerson from his own cultures, and with the help of Mr. Shafer, from the coöperative cultures also grown at Cornell.

The following measurements were made of each plant collected:

1. Length of the tassel and each internode from the tassel to the coleoptile (where possible). These measurements were totalled and compared with a separate measurement of total height of plant as a check.
2. Diameters in two directions at right angles to each other of the upper, middle and lower part of every third internode from number 1 just below the tassel to the soil level. Below this point the adventitious roots swell the short internodes beyond their original diameters.
3. Leaf sheath lengths.
4. Leaf blade lengths.
5. Leaf blade widths at the base and at 1/4, 1/2, 3/4, and 7/8 the distance from base to tip of leaf blade for every third leaf beginning with leaf 1 just below the tassel. The lower leaves were unfortunately dry at maturity, and it is planned to make some provision for measuring them at an earlier date another year.

* *Editor's note.* The following group of eight papers constitutes brief reports to date of the progress of research assisted by grants from the Penrose Fund of the American Philosophical Society.

Comparisons of average plant proportions for those dwarf and normal height plants collected are given for four of the dwarf and dwarf-like corn types in the accompanying graphs

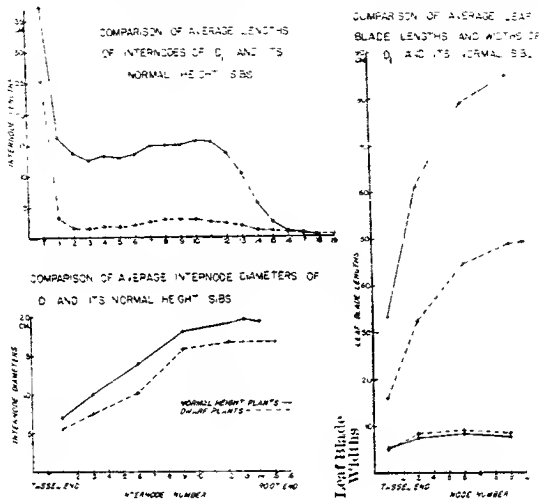


Fig. 1. Graphs for D_1.

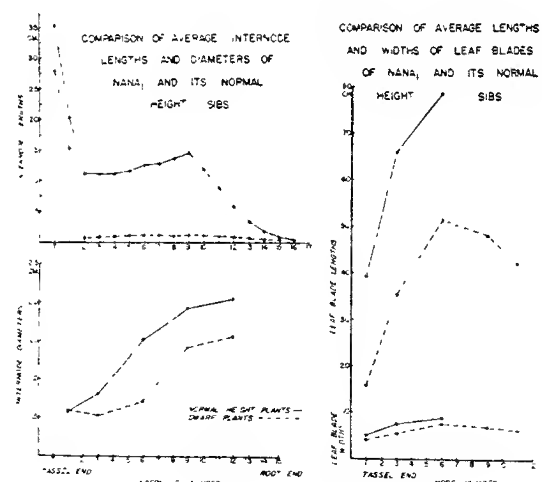


Fig. 2. Graphs for nana$_1$.

(Figs. 1, 2, 3, 4). A dwarf and normal height pair of plants with and without leaves is shown in the photographs accompanying the graphs for two of these five cultures (Figs.

5, 6, 7, 8). It will be seen from the graphs that while the ratio of width to length of leaf is much greater in the dwarf

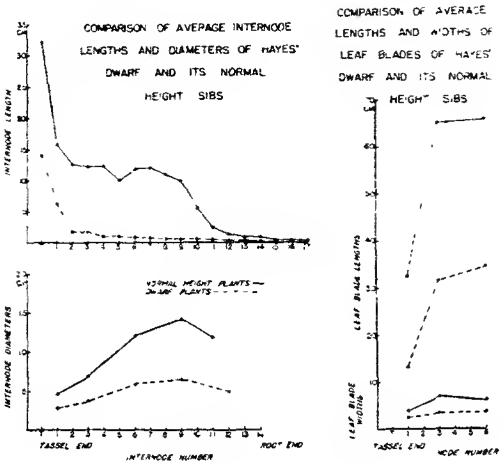


FIG. 3. Graphs for Hayes' dwarf.[1]

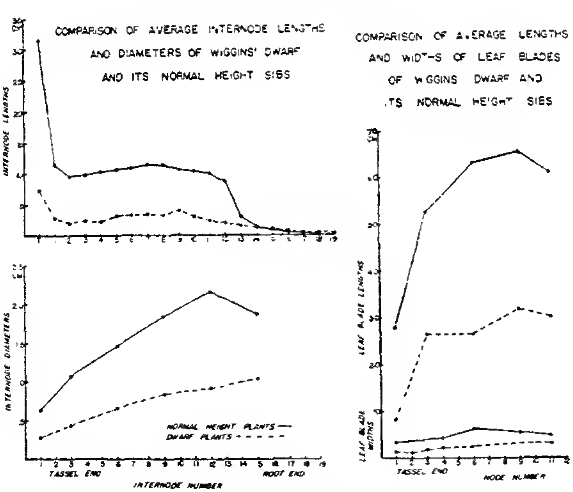


FIG. 4. Graphs for Higgin's dwarf.[2]

than in the normal for d_1, and $nana_1$, it is very nearly the same for both normal and dwarf types in Hayes' and Wiggins'

[1] This dwarf, provided by Dr. H. K. Hayes, arose, apparently as a mutant, from cultures grown at the University Farm, University of Minnesota, in 1932, but has not been tested by crossing.

[2] This dwarf, also apparently a mutant, appeared at Cornell University in a pure culture grown by Dr. Higgins.

dwarf types. In general the ratio of internode diameter to length is greater in the dwarf than in normal types.

Although the quantitative analysis of the cellular differences between dwarf and normal types is not yet complete the following differences are recognizable. (The present discussion deals with differences observable in cross-sections of the internodes.) It was found that d_1 and $nana_1$ have, in general, smaller cell size in the ground parenchyma and vascular tissues than do their normal sibs (in confirmation of the preliminary data given in the prospectus) if comparable parts are considered. It will be noticed that the average diameter of internode 1 in the $nana_1$ culture was nearly the same for both dwarf and normal while internodes 6 and 12 were considerably less in diameter in the dwarf than in the normal sibs. When the cell diameters of the normals and dwarfs are compared for each of these internodes it is found that there is very little, if any, difference between the size of the ground parenchyma cells from internodes 1 of the dwarf and normal while for internodes 6 and 12 the ground parenchyma cells have noticeably greater diameter in the normals than in their dwarf sibs. On the other hand, at least the vessels of the vascular strands, are noticeably larger in the normals in internodes 1, as well as, in internodes 6 and 12. The same relations were found between gross internode diameter and diameter of ground parenchyma cells for Hayes' dwarf and its normal sibs. In d_1 gross internode diameters and diameters of ground parenchyma cells and vessels were larger for all internodes examined in the normal than in any corresponding internodes of the dwarf.

No generalizations will be attempted at this point except to point out that there seems to be a very suggestive relation between cell diameters and gross internode diameters in some cases, whether one compares two internodes of the same plant or comparable internodes of the dwarf and normal plants.

Numerous refinements have suggested themselves such as better methods for determining comparable internodes during the course of this study. It has become especially evident

PLATE I

FIG. 5. Nana$_1$ and its normal sib.

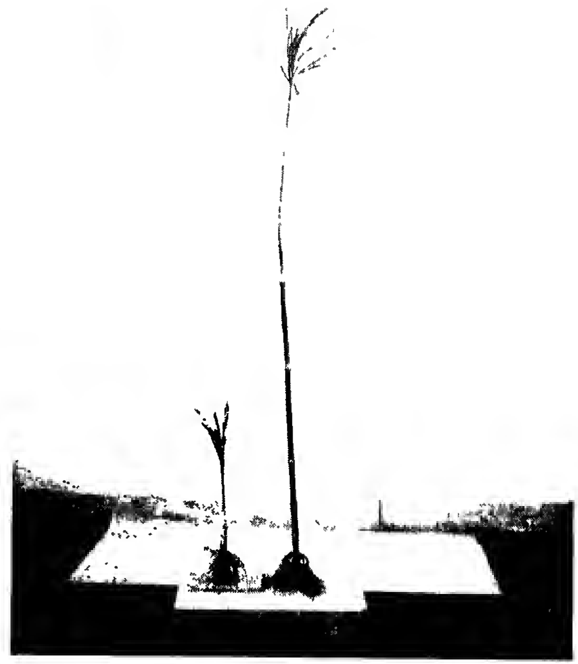


FIG. 6. Nana$_1$ and its normal sib with leaves removed.

PLATE II

FIG. 7 Wiggins' dwarf and its normal sib.

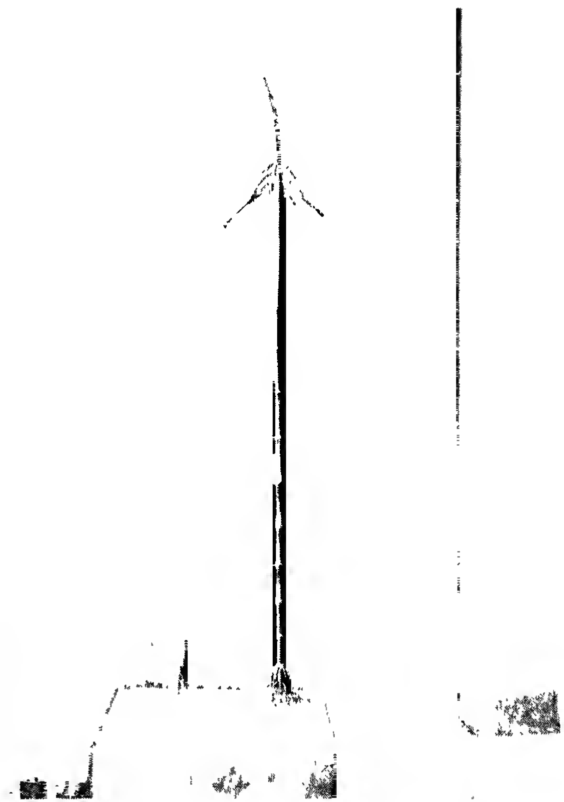


FIG. 8 Wiggins' dwarf and its normal sib with leaves removed.

that it is of first importance to have pure cultures in this work segregating only for height. For that reason Dr. Emerson very kindly crossed several dwarf types onto two pure lines for me last summer and further crosses are being made so that we can obtain suitable material in pure culture as soon as possible. The writer would welcome any criticisms or suggestions relative to further work on the problem.

In conclusion I should like to express my appreciation for the constructive criticism given me by Dr. Eames and Dr. Emerson and for the help in measuring and collecting so ably rendered by Mr. John Shafer and Miss Iris Trump.

Cornell University

EVAPORATION AND RAINFALL STUDIES IN THE NORTHWEST MINNESOTA LAKE REGION

J. C. JENSEN

During the extreme drought conditions of August and September, 1934, the writer was privileged to travel extensively through Nebraska, eastern Colorado and Wyoming, and southern and eastern South Dakota, where observations were made on the paths of local thunder storms, changes in water table, the rate of surface evaporation, and related data, most of which was obtained from U. S. Weather Bureau officials and coöperative observers.

Studies were also made of rainfall records during the thunderstorm season from a selected list of stations in central and eastern South Dakota, which brought out the fact that the departures from normal rainfall for the months April to August, 1934, inclusive, were much less in the lake region around Watertown than in the open plains directly west. This suggested the explanation that the additional moisture added to the atmosphere, which was shown by evaporation tables at Lincoln and North Platte. Nebraska, to be almost an inch in a single day under hot-wind conditions, might be sufficient to raise the relative humidity of ascending air currents in a thundercloud to such an extent that moisture

condensed in the upper portion of a "heat" thunderstorm would be able to reach the earth without reëvaporation. Further proof of this proposed theory was found in the Platte Valley where the number of "dry" thunderstorms was materially less than on the uplands near by, the natural consequence of the higher humidity which prevails above the irrigated areas of the valley.[2]

An appropriation for the purpose of continuing the investigations of the preceding summer having been obtained from the Penrose Fund of the American Philosophical Society, further study was made of rainfall records during the thunderstorm season in a number of typical locations for the purpose of finding a location which would promise the maximum of data in a limited time. Table I shows the average

TABLE I

1904–30	May	June	July	August	Total
Watertown, S. Dak.	[illegible]	3.04	2.7[illegible]	2.56	11.94
Alexandria, Minn.	3.27	3.9[illegible]	3.48	2.91	13.65
Fergus Falls, Minn.	3.71	4.38	3.45	2.80	14.34
Huron, S. Dak.	3.07	3.7[illegible]	3.12	2.38	12.36
Moorhead, Minn.	2.78	3.[illegible]4	2.99	2.7[illegible]	12.31
Fort Ripley, Minn.	2.78	3.[illegible]5	2.94	2.81	12.48

rainfall for the thunderstorm months of May, June, July, and August for a selected list of stations for which continuous records are available since 1904. It will be noted that over a long period of time the precipitation does not vary much among these various stations. This bears out the commonly accepted theory that the major portion of the precipitation in the Mississippi and Missouri Valleys is the result of moisture carried in from outside sources, chief of which is the Gulf of Mexico.

Table II gives the rainfall for the same stations for the dry year of 1910, and Table III data for the drought season of 1934. The relatively high rainfall at Watertown in both instances will be noted, also the low rates at Huron, Moorhead,

[2] Jensen, *Bull. Amer. Meteor. Soc.*, 16, p. 143, May 1935.

and Fergus Falls. Watertown is in the midst of the South Dakota Lakes, while Huron is far to the west. on the plains. Likewise Moorhead and Fergus Falls are west of the large

TABLE II

1910	May	June	July	August	Total
Watertown	0.50	2 78	3.16	3.17	9.61
Alexandria	1.07	1.65	3.78	3.08	9.57
Fergus Falls	0.63	1.14	1.89	0.78	4.44
Huron	1.05	2.54	0.48	1.43	5.50
Moorhead	0.92	0.83	0.83	1.39	3.97
Fort Ripley.	0.95	1.87	1.86	2.31	6.99

TABLE III

1934	May	June	July	August	Total
Watertown ..	0.99	3.51	5.65	2.81	12.96
Alexandria.	0.63	4.81	1.41	1.43	8.28
Fergus Falls.	1.05	3.50	2.09	1.99	8.63
Huron .	0.65	2.52	2.11	1.45	6.73
Moorhead.	1.15	3.93	0.80	0.73	6 61
Fort Ripley.	0.93	4 45	1.12	2.56	9.06

group of lakes in northwest Minnesota. while Alexandria lies southeastward in the path of storms approaching from the northwest. Fort Ripley is a sufficient distance east of this group of lakes to make it largely independent of their influence. These figures would indicate a definite increase in rainfall during dry seasons for points adjacent to lake areas. (Results expressed in inches.)

Method of Attack

Since the objective for the summer of 1935 was to determine, if possible, whether there were well-defined. though small increases in the thunderstorm precipitation within a distance of 20 to 30 miles from water areas of considerable extent, it was decided to distribute rain-gauges at intervals of about 10 miles over a selected region about 50 miles square with a battery of microbarographs. recording thermometers,

and recording hygrometers along the western front of the area under observation, and at one or two other points to the eastward.

Area Selected

In selecting an area for study, the lake regions in northeastern South Dakota and in the vicinity of Dawson, North Dakota, were first examined. The lakes around Watertown, South Dakota, were about a foot higher than in 1934, but Lake Madison still remained practically dry. Most of the

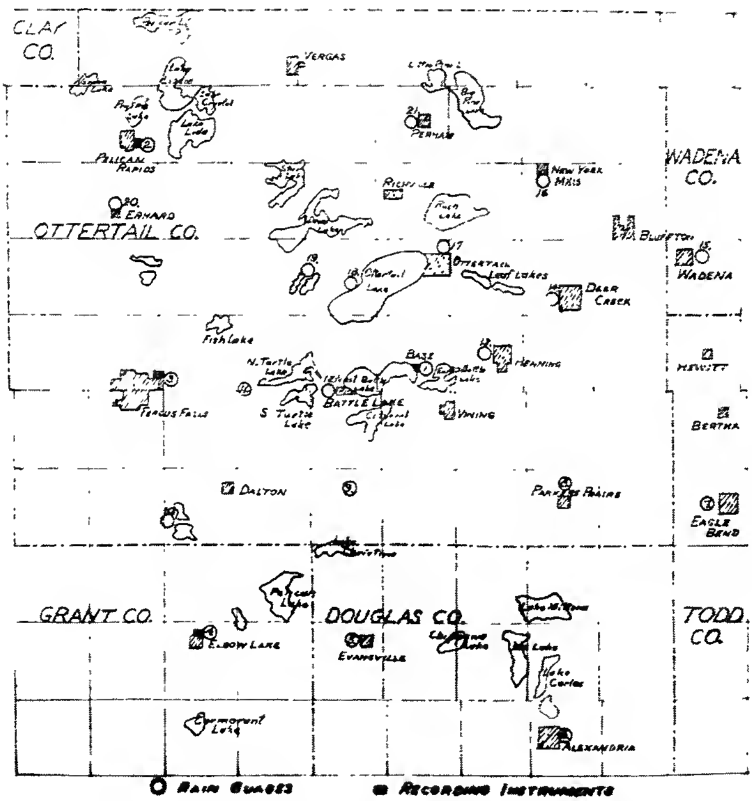


Fig. 1. Map showing territory covered by this investigation. Key: 1. Base station on West Battle Lake. 2. Pelican Rapids. 3. Fergus Falls. 4. Elbow Lake. 5. Evansville. 6. Alexandria. 7. Eagle Bend. 8. Parker's Prairie. 9. Lind Farm. 10 Haarsted Farm. 11. Underwood 12. Battle Lake. 13. Henning. 14. Deer Creek. 15 Wadena. 16. New York Mills. 17. Ottertail. 18. Amor. 19. Twin Lakes. 20. Erhard. 21. Perham.

North Dakota lakes are so shallow that the exposed area varies considerably between showers and might be materially reduced by a few days of hot-winds.

The large number of lakes in Ottertail County, Minnesota, which include Ottertail, East and West Battle Lakes, Rush Lake, Clitherall Lake, the Leaf Lakes, Lake Lida, and many others, having a total of 83.2 square miles, seemed to adapt this region especially for the purposes of this study. Accordingly, head-quarters were established near the east end of West Battle Lake on July 25. The site chosen gave easy access to highways in every direction, and its lake front extending six miles westward afforded an unusually good opportunity to observe approaching thunderstorms (Fig. 1).

Equipment

The equipment at the Base station consisted of a cup anemometer, tipping-bucket rain-gauge of the U. S. Weather Bureau type, a microbarograph, a combined thermograph and recording hygrometer, and a galvanometer and antenna for the measurement of field changes caused by lightning discharges. The anemometer and rain-gauge were installed on the sandy beach 300 ft. from the lake shore. The anemometer had good exposure to west and south but was sheltered by timber on the north. The combined thermograph and hygrograph was placed on a platform on the north bank of the lake 400 ft. from the shore and 60 ft. above the lake level. Additional equipment which was used for field work as well as for checking recording instruments consisted of a high-grade sling psychrometer, a portable anemometer of the vane type, a stop watch, etc. Mr. C. E. Kissinger, the coöperative observer at Fergus Falls, was supplied with a microbarograph, a thermograph, and a recording hygrometer in addition to his regular equipment. Similar instruments were installed at the home of Dr. R. E. Hagen at Pelican Rapids, also a wet and dry bulb hygrometer and a stationary rain-gauge. A microbarograph, rain-gauge, and hygrometer were supplied to Mr. Hans Germundson at Elbow Lake.

Common rain-gauges were installed at Underwood, Erhard, Eagle Bend, Parker's Prairie, Ottertail, Amor, Battle Lake, the Haarsted farm seven miles south of Fergus Falls, and the Lind farm eight miles south of Clitherall. Mr. E. F. Ehlers, cooperative observer at Alexandria, and Mr. Frank Ioset, cooperative observer at Wadena, kindly mailed in weekly reports of local rainfall at their stations. Because of the large areas covered by the rain-gauges, it was impossible to make personal check on each gauge after every shower. The recording instruments were serviced each Monday and all instruments checked, notations being made on the record of such variations from the correct values as were found. This necessitated a drive of about 160 miles and made a heavy day's schedule, as rain-gauge reports on the circuit were also collected.

Rainfall Records

In Table IV are shown the accumulated totals of rainfall for the month of August for 18 of these stations. The rainfall was heaviest in the southeastern part of the area under

TABLE IV

Rainfall Record
August 1935

Base	3.82	Henning	2.95
Fergus Falls	3.42	Deer Creek	3.82
Underwood	3.37	New York Mills	3.19
Pelican Rapids	1.85	Perham	2.57
Erhard	1.88	Ottertail	3.61
Eagle Bend	3.71	Amor	2.75
Parker's Prairie	3.46	Battle Lake	4.36
Evansville	4.77	Alexandria	5.07
Elbow Lake	3.57	Wadena	3.81

observation and lightest in the northwestern part. Micro-barograph records showed that the general path of the thunderstorms observed was from northwest to southeast. They would thus enter the area on the western front from Pelican Rapids to Fergus Falls and continue southeastward over the Base station and toward Parker's Prairie, Alexandria, and Wadena. The totals for Pelican Rapids and Erhard, stations eight miles apart, agree within 0.03 of an inch. Eagle Bend,

Parker's Prairie, and Elbow Lake are also in close agreement, the additional rain at Evansville being largely due to one heavy local shower. Perhaps the most striking departure from normal is the total of 2.75 inches for Amor, which lies west of Ottertail Lake, while the total for the town of Ottertail, two miles east of the north end of the lake, showed 3.60 inches.

While the rainfall data which it was possible to gather in so short a time are admittedly insufficient to establish as proved the general thesis that the passage of local thunderstorms over a lake area increases the precipitation, they are in agreement with that thesis.

Hot-Winds

The week of August 12 to 19 was characterized by hot dry winds from the southwest, especially on the 12th, 13th, and 14th. In Table V is shown the temperature and relative

TABLE V

	August 13			August 14			August 15		
	Temp	Humidity		Temp.	Humidity		Temp	Humidity	
Pelican Rapids									
8 a.m. . . .	62°	73%,	4.5 gr. cu. ft.	70°	60%,	4.8 gr.	75°	53%,	5.0 gr.
4 p.m. .	93	19	2.9	99	21	4.1	100	22	5.6
Fergus Falls									
8 a.m. .	68	50	3.7	74	21	4.1	78	48	4.9
4 p.m. . .	84	31	3.8	94	32	5.5	96	35	6.2
Base									
8 a.m. .	66	55	3.9	72	58	5.0	77	54	5.8
4 p.m. .	88	42	6.0	92	43	6.8	89	49	7.1

humidity at 8 a.m. and 4 p.m. for each of the three days, as obtained from the recording instruments at Pelican Rapids, Fergus Falls, and the Base station. The absolute humidity, as computed from standard meteorological tables, is also given. The close agreement between Base station and Fergus Falls at 8 a.m. will be noted. The deviation in the case of Pelican

Rapids in the early morning was due to the fact that the kiosk there was in the shade until about 9 a.m. The lower temperatures and higher absolute humidity at Base station at 4 p.m. are definite proof of the larger moisture content of the surface air in wind blowing over a lake, and show a considerable increment of moisture from that source.

In order to determine whether the moisture content of the air for the entire month of August varied materially at the three recording stations, the total areas under the thermograph and hygrograph curves were computed by means of a planimeter and averaged by dividing the total area by the time coördinate for each week. From these values the absolute humidities were computed. The accumulated totals thus obtained show only such differences as might be expected from instrument variations, differences in altitude, etc. The large variations indicated during the hot-wind conditions of Table V are lost when added to the total moisture content of the air as recorded over a longer period.

The planimeter was again employed to obtain an estimate of the lake areas in Ottertail County. Taking only the larger lakes, the total is 83.22 square miles. Many of the smaller ones shown on the map are now completely dry, and some of the larger ones have evaporated until their total area is considerably less than that which was measured. The above total may therefore be considered as approximately correct. On the afternoon of August 14, sling psychrometer observations in a stubble field six miles north of Battle Lake and two miles from the south shore of Ottertail Lake gave a wet bulb temperature of 70° and a dry bulb temperature of 96° F. at 4:35 p.m. Thirty minutes later, similar readings on the northern shore of Ottertail Lake were 71° and 87° F. This gave relative humidities for the two points of 28 per cent and 46 per cent respectively, and absolute humidities of 5.1 and 6.6 gr. cu. ft. This makes a difference of 1.5 gr./cu. ft. of moisture in the air coming over the lake as compared with that blowing over the stubble field. If we assume that this moisture increment decreases linearly from the earth upward,

reaching zero at an altitude of 500 feet, and replace the large number of lakes measured by a single square lake about 9 miles square, and then compute the total amount of air which would travel over such a lake at the average prevailing wind velocity of 23 miles per hour for August 14, it is found that the total amount of water which should have been evaporated from this lake surface in the 24 hours was 0.66 of an inch. The records of Mr. Erickson, who has charge of a lake-level gauge on the Twin Lakes near Amor, show that these lakes, which have neither inlet nor outlet, lost 0.87 of an inch of moisture on August 14 and 15. The lake was too rough on the evening of the 14th to obtain a reading. Since the evaporation would be considerably higher in the afternoon than during the night, the computed value above is in good agreement with the observed loss of water from Twin Lakes.

It has been shown by Fitzgerald.[1] that the evaporation from a surface exposed to wind in rapid motion may be computed from the empirical equation, $E=(p_s-p_0)(1+1/2w)$, where "E" is in inches/minute, "p_s" is the saturated vapor pressure at the given temperature, "p_0" the vapor pressure observed, and "w" the velocity of the wind in miles hour. Substitution of the data used in the computation for exposed lake areas for the same afternoon gives a total evaporation of 0.57 of an inch in 24 hours, which is in fair agreement with the result obtained by the other method.

It is evident, therefore, that very considerable quantities of moisture are evaporated from lakes and ponds under the hot-wind conditions already described, the set of observations chosen being only one of many which were obtained, not only in the vicinity of Ottertail Lake, but from other points scattered over the area studied. If the presence of such a lake can increase the relative humidity by 16 per cent and the absolute humidity by 29 per cent, at the same time lowering the temperature of the air 9° F., it seems logical to expect that heat thunderstorms supplied with air carrying this additional load of moisture and lower temperature should produce more

[1] Fitzgerald, *Trans. Amer. Soc. Civ. Eng.*, **15**, p. 581, 1886.

precipitation than had the same clouds passed over an equal area of hot dry ground; also that the probability of reëvaporation of the falling raindrops would be materially lessened, for computations based on the Neuhoff diagram show that air at 87° F. and 46 per cent relative humidity must rise to a height of 2700 meters, expanding adiabatically, to reach the saturation point, while air at 96° F. and 28 per cent humidity must rise 1100 meters higher, or a total of 3800 meters (1.68 and 2.36 miles, respectively).

Thunderstorms

The battery of microbarographs described above made it possible both to follow the paths of individual storms and also to note the variation in intensity of each storm and the number of disturbances which accompanied each low area, a technique reported in a previous article.[1] Figure 2, which is a reproduction of the microbarograph records for the afternoon and evening of August 19, may be considered as typical. At the Base station there was a rapid fall of the barometer until 3 p.m., followed by minor fluctuations. A shower fell at 5 p.m., with a second heavy rain between 7 and 8 o'clock, and a lighter storm at 11 p.m. The barometric fluctuations were much greater at Pelican Rapids and began there an hour earlier, with 0.68 of an inch of rain between 3 and 4 p.m., and 0.30 more at 7 p.m. At Elbow Lake and Evansville rains fell in the afternoon before 6 p.m., the heaviest shower occurring at 5 p.m. Fergus Falls reported only 0.61 of an inch for the entire day, the center of the showers having passed toward the southwest. The whole countryside was literally filled with thunderstorms, with local showers of 3 to 10 miles width scattered over the entire area.

The rapid fluctuations in temperature and relative humidity of the atmosphere are well illustrated in figure 3, which resulted from a thunderstorm accompanied by considerable hail at the Base station at 4:50 p.m. on August 9. The temperature dropped from 88° to 62° F. within a few

[1] Jensen, *Jour. Franklin Institute*, **216**, p. 707, 1933.

minutes after the storm began, but rose again to 75° when the clouds cleared away at 6 p.m. The relative humidity rose

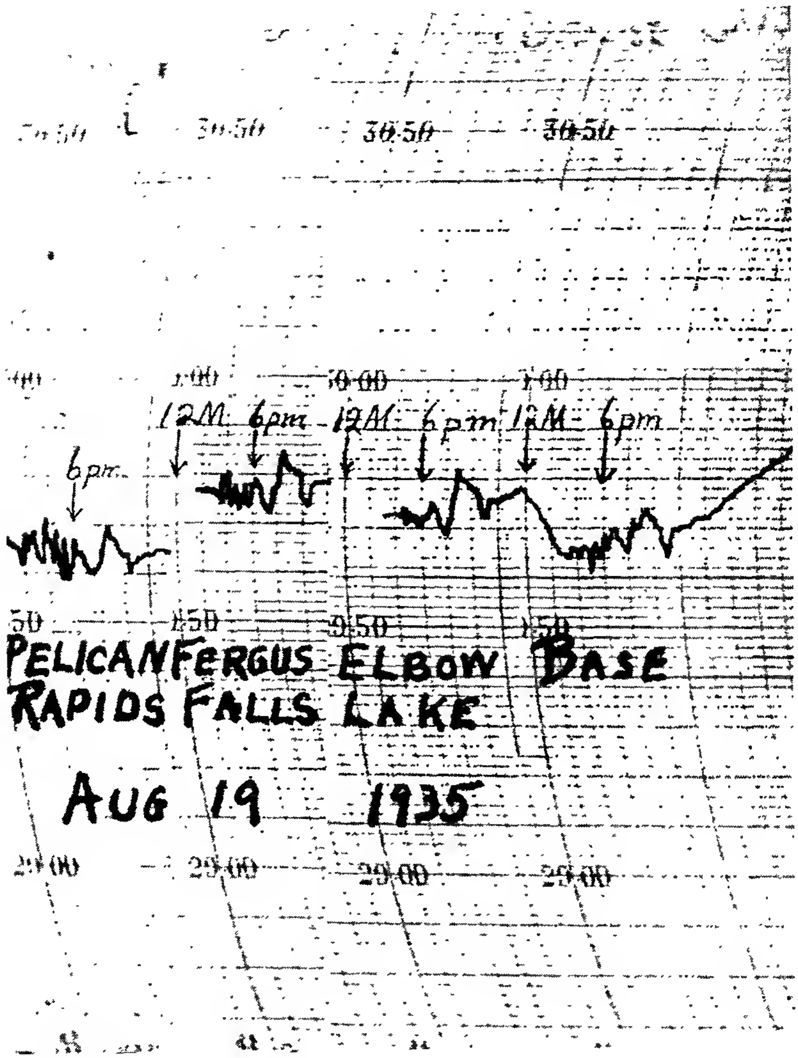


FIG. 2. Microbarograph records for the afternoon of Aug. 19, 1935. (All instruments were set to read one inch too high.)

rapidly from 61 per cent to 94 per cent simultaneously with the drop in temperature, and remained high in the instrument

case for several hours afterward, due to the fact that some of the rain blew through the latticework of the shelter. The minor fluctuations in humidity immediately before the storm began were the result of passing clouds.

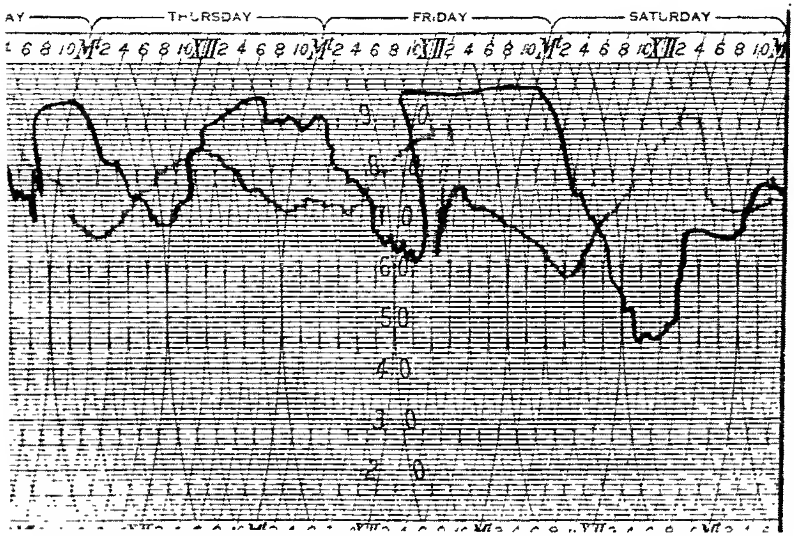


FIG. 3. Temperature and humidity records for thunderstorm on Aug. 9 at 4:50 p.m. The heavier line gives relative humidity in per cent.

LIGHTNING DISCHARGES

An attempt was made to get additional data on the branching of lightning and the corresponding changes in the electrical field.

The most interesting photographs obtained were a series from a cloud which passed directly south of the Base station at 1 a.m. on August 24. Two pictures from this series are shown in figures 4 and 5. The discharges to ground were unusually brilliant with many fine streamers, but the outstanding characteristics of them all were the long fine discharges toward the northwest into the front of another storm-cloud which was passing southeastward from the southern part of Ottertail Lake. The distant discharges from this second cloud can be seen at the right of the picture in figure 5.

PLATE I

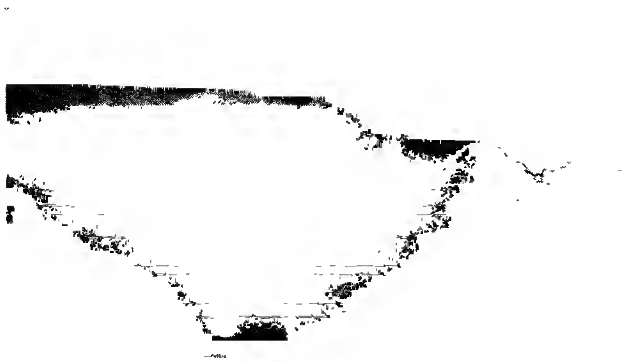


FIG. 4. Lightning discharges, 1 a.m., Aug. 24, 1935. Storm passed from 1 to 2 miles south of the observer.

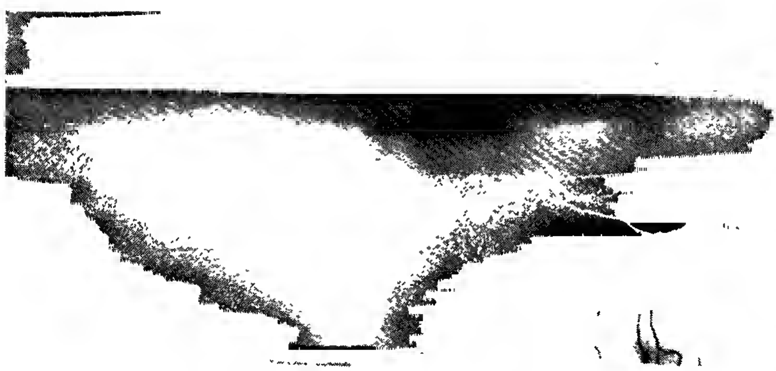


FIG. 5. Same storm as figure 4. Long streamers almost directly overhead, discharging into second cloud advancing south of Ottertail Lake.

Some of these streamers must have been at least two miles long, their length being equal to three or four times the height of the active portion of the cloud from which they came.

ACKNOWLEDGMENTS

The writer is indebted to the University of Nebraska and to the U. S. Weather Bureau for the loan of some of the instruments used in this investigation. Others were purchased by grants from the Hodgins Fund of the Smithsonian Institution and from the Bache Fund of the National Academy of Sciences, all of which have been used in previous investigations. The fine coöperation of U. S. Weather Bureau observers, as well as that of sixteen others who were responsible for the rainfall records in their respective communities, was greatly appreciated.

The project itself was made possible by a grant from the Penrose Fund of the American Philosophical Society, which provided for the purchase of indispensable instruments not otherwise available and for incidental expenses. All of the above are gratefully acknowledged.

NEBRASKA WESLEYAN UNIVERSITY,
LINCOLN, NEBRASKA,
December 14, 1935

SECOND REPORT OF PROGRESS ON RESEARCH IN COSMIC-TERRESTRIAL RELATIONS

HARLAN T. STETSON

Since the first report[1] considerable progress has been made in both of the main divisions outlined in the program of cosmic-terrestrial relations. Under the first division which deals with geophysical problems, the study of the apparent deflections of the "vertical" as affected by the position of the moon has been pursued through new investigations of variation in latitude during the years for which variations in longitude previously reported[2] have been made.

[1] *Miscellanea*, Volume I, Number 1.

[2] "Further Investigations of an Apparent Lunar Effect in Time Determinations" by A. L. Loomis and H. T. Stetson. *Monthly Notices* of the Royal Astronomical Society, **95**, Number 5, March 1935.

With the issuance of Results of the International Latitude Service, Vol. VII, data have become available for the study of small variations in latitude as affected by the moon's hour angle and declination for three principal stations of the International Latitude Service—Ukiah, Mizusawa, and Carloforte. The analysis of all of the available observations in 1928, 1929, and 1930 have involved the study of values of latitude determined with the zenith telescope from 17,450 pairs of stars. A card catalogue was prepared giving the mean value of latitude from the station in question for each night of observation corrected for the known wandering of the pole. The value of the latitude so determined has, in general, been dependent upon the observation of 10 to 16 pairs of stars. From the right ascension of the stars utilized for the date in question, the Greenwich Civil Time and the hour angle and declination of the moon have been calculated corresponding to the mean right ascension of the groups of stars involved in a single night's observation. As was done in the case of a similar study previously published [1] the cards were then divided into three main divisions corresponding to declinations of the moon: north of the equator $+12°$ to $+28°$, south of the equator $-12°$ to $-28°$, and in the equatorial region $-12°$ to $+12°$ declination. The cards in each of these three classifications were then sorted in order of increasing hour angle of the moon. Each division was again divided into approximately 12 equal groups. The mean value of the lunar hour angle for each of these 12 groups in each of the three classes was then ascertained for all of the three stations. Latitude against lunar hour angle was then plotted giving a series of nine curves. In the case of Ukiah two maxima for the value of latitude are indicated corresponding to the

[1] "Further Studies of the Lunar Correlation with Latitude" by H. T. Stetson. *Transactions of American Geophysical Union*, National Research Council, 1932. "Investigation of the Moon's Influence on Latitude" by H. T. Stetson. *Transactions of American Geophysical Union*, National Research Council, 1931. "Study of Earth Tides from the Variation in Latitude" by H. T. Stetson. *Transactions of American Geophysical Union*, National Research Council, 1930. "Variation of Latitude with the Moon's Position" by H. T. Stetson. *Nature*, **123**, Number 127, 1929; *Science*, 69, Number 17, 1929. *Earth, Radio, and the Stars* by H. T. Stetson. Chapter III, pages 27–47

meridian passage of the moon both above and below the horizon. Corresponding minima occur near the lunar hour angles 6^h and 18^h. The range in value is of the order of $0''.05$. A similar curve is found in the Carloforte observations corresponding to south declination of the moon. Further details will be published elsewhere.

A comparison with curves derived from studies of earlier years seems to add support to the effect of the moon on small displacements of the geodetic position of the station involved. The reduction of additional years to close the gap between the series of the earlier studies and the present investigations is desirable to obtain a continuous picture of such lunar effects as may exist. It appears possible that small displacements of the earth's crust result which are not completely restored causing variations in the pattern of these curves from year to year.

The reduction of the comparisons of small variations in longitude with the hour angle of the moon from the interchange of transatlantic time signals during the years 1931, 1932, and 1933 is still awaiting publication. It is hoped that the data from the International Latitude Service may become available soon for studying the north and south components during these same years.

Again there is indication that a change in phase of the tidal pattern occurs in east and west directions with the passing of time. The recent announcement by Dr. Foote of the Gulf Refining Research Company of a rise and fall in the earth's crust at Pittsburgh of 23 inches [1] during the lunar day adds considerable support to the hypothesis of earthtides involving crustal displacements of greater magnitude than would be supposed from classical theories. Since the results of the Gulf Laboratory's research have been based on gravimetric measures with an order of accuracy of 10^{-8} g., we have interesting and independent evidence for movement in the earth's crust which has considerable bearing on the present

[1] "Tide in Rocks at Pittsburgh" by P. D. Foote. *Science*, November 1, 1935, **82**, Supp. page 8.

investigations. It should again be emphasized that geodetic measurements depend upon the direction of the vertical which is very sensitive to horizontal displacements. The question of tilts of the earth's crust cannot enter into the determination of geographical coördinates from astronomical observations since the zenith telescope determines the vertical with respect to the earth's equipotential surface and not to the slope of the ground.

The whole question of crustal movements is so important that an investigation has been made of the original observations of Börgen and Copeland referred to by Jelstrup relative to the alleged change in longitude of 615 meters in the position of Sabine Island off the northeast coast of Greenland between the years of 1870 and 1932. It appears that while the 1870 observations could not attain the accuracy of the 1932 observations in the determination of longitude of the station occupied, nevertheless, the value of the longitude determined was based upon a number of moon culminations and many occultations of stars. It appears, therefore, that the probable error of 80 meters is justified for the 1869 and 1870 observations and about 22 meters for the 1932 observations. Even allowing for the worst possible combination of errors, a comparison of geographic coordinates of the stations in question from the two determinations indicates a drift westward of as much as 250 meters in the intervening sixty-two years. Examination of the original publication brings to light also an apparent movement south of about 100 meters during the same interval. This fact has received little attention in criticism of the results of the Greenland expedition.

A continued study of the relation of seismic disturbances to lunar tidal forces is in progress. A note with a graph summarizing the relationship between the occurrences of deep focus earthquakes and the lunar tidal force in operation at the time has been published since the first report.[1] The

[1] "The Correlation of Deep-Focus Earthquakes with Lunar Hour Angle and Declination" by H. T. Stetson. *Science*, November 29, 1935, 82, pages 523–24.

examination of the chance distribution of errors for the data there presented gives little encouragement for any explanation of the curve on fortuitous grounds. As a single coincidence it is interesting to note that the large earthquake in New England on November 1, 1935, occurred when the horizontal component of the lunar tidal force in a northeast-southwest direction was at its maximum. This led to the supposition that it was of deep-focus origin, a supposition fully confirmed when sufficient seismographic records had been reported.

The possibility of investigating the magnitude of tides in the earth's crust through the operation of micrometric tide gauges suitably placed in oil wells or artesian wells has been further investigated but thus far an ideal location for the installation of such apparatus for best results has not been found.

The investigation of ionospheric effects of cosmic origin comprising division two of the general research program has been continued. Automatic records of the relative field intensities of the Chicago station WBBM as received in the vicinity of Boston have accumulated and cover some 2000 observational hours since the last report. The reduction of these records is in progress. Using improved apparatus installed at the Institute since the last report, systematic observations have been made of conditions in the ionosphere as determined from observations of the performance of the transatlantic carrier waves utilized in commercial telephony. On many days such unusual conditions have been noted that the carrier wave traveling over the long arc around the earth interferes with the corresponding wave traveling over the short arc across the Atlantic. The correlation of conditions for this interference with solar and cosmic phenomena has presented a new means of investigation in this field. Other coöperating stations are now reporting observations which are becoming available for extending these ionospheric researches in a more comprehensive manner.

Pursuance of the investigation of the apparent group velocity of radio waves across the Atlantic has brought to

light not only a secular variation in the apparent group velocities as derived from the intercomparison of time signals but the apparent dependence of velocity upon the magnetic characteristics of the earth for the region of transmission. A study of available data from the 1926 longitude campaign has yielded results that show an increase in velocity with a decrease in the value of the horizontal component of the earth's magnetic field over the region of propagation. A study of velocities in respect to magnetic dip shows that with increasing value of dip there is a decrease in the effective group velocity of the radio waves. One may conclude that in an exact determination of longitude it is not safe to assume that radio waves travel with the velocity of light over the great-circle arc connecting the two stations involved. Allowance for transmission time on such a basis introduces errors often times of greater magnitude than the precision of the observations should allow. A technical paper under the title "On the Effective Group Velocities of Radio Time-Signals and the Apparent Variability of Velocity with the Region of the Earth Traversed" appearing in the September 1936 issue of the *Journal of Terrestrial Magnetism and Atmospheric Electricity* gives the details of this investigation. Another paper giving corroborating evidence for a lunar effect on the intensity of radio transmission is in preparation. There appears to be evidence for electronic tides in the ionosphere which are based upon the large number of hours of observations that have been obtained from not only WBBM Chicago but from KFI Los Angeles.

Two papers dealing with results of solar and lunar effects on the ionosphere and other related phenomena were presented at the midwinter meeting of the American Association for the Advancement of Science at St. Louis. The titles were "Note on the Present Sun-Spot Cycle" and "Investigations of Certain Cosmic-Terrestrial Relations." A brief summary of one of these has appeared in *Science*,[1] and of the other in the *Bulletin of the American Meteorological Society*, April 1936.

[1] "Note on the Present Sun-Spot Cycle" by H. T. Stetson. *Science*, February 28, 1936, 83, page 205.

There has been presented to the Chairman of the Committee on Grants an outline of a proposed memoir which could be prepared to give a technical summary of the work accomplished in this new field and which would emphasize the close interrelation of the problems concerned, each one of which directly or indirectly involves progress in all.

It is believed that the problems that are being attacked in the field of cosmic-terrestrial relations are fundamental and will prove to be of increasing significance as the investigations continue. A satisfactory solution of many of the puzzling questions may not be immediate but it is believed that the methods of observation and attack are sufficiently promising to yield worthwhile results. It is to be hoped that sufficient support may soon be found for continuing and extending the investigation of these problems which offer unusual opportunities for further study.

Acknowledgment is due Professor John A. Miller, under whose direction the work has progressed, for his interest and encouragement, to Dr. A. Hamilton Rice for the space and facilities offered at the Institute of Geographical Exploration, to the National Academy of Sciences, the Rumford Committee of the American Academy of Sciences, and the American Association for the Advancement of Science, to each of these for previous grants for assistance and apparatus, as well as to the Committee on Grants of the American Philosophical Society.

Harvard University,
Institute of Geographical Exploration,
March 1936.

INTENSITY DISTRIBUTION IN ELECTRON DIFFRACTION PATTERNS

K. LARK-HOROVITZ, H. J. YEARIAN AND J. D. HOWE

Feb. 1, 1935 to Feb. 1, 1936.[1]

ABSTRACT

A Universal camera has been constructed for the production of electron diffraction patterns of single crystals, powders, liquids and vapors. It is possible in this camera to take diffraction patterns from a surface orientated at the incoming beam in different directions, as well as diffraction patterns produced by penetration of the material. Investigations can be carried out from liquid air temperature up to 400° and the changes in structure can be recorded, without changing the vacuum, by an automatic mechanism allowing the succession of 49 exposures with an exposure time which can be pre-selected and automatically provided.[1]

The material was used mostly in the form of thin films which have been prepared with a new method which allows the production of unsupported films only a few atoms thick.[2] Using this method it has been possible to find the origin of "extra rings" in electron diffraction patterns as due to surface layers.[3]

Electron diffraction patterns have been obtained with voltages ranging from 80 kv. down to 15 kv. The results show that the behavior at high voltages is entirely different from that at low voltages.

Atom factor determinations for copper in pure copper and in cuprous oxide, for zinc, cadmium, gold, silver and palladium[4] have shown that the wave mechanical formula

$$F_{el}(\vartheta) = \frac{Z}{2E}\,\frac{1 - F_r}{\sin^2\vartheta/2} = \frac{1}{\sqrt{E}}\Sigma(2l + 1)P_l(\vartheta)\delta_l$$

as given by Mott is fulfilled at the higher voltages. At the lower voltages one would expect that this formula above should be replaced by the better approximation as given by Massey and Henneberg

$$F_{el}(\vartheta) = \frac{1}{2i\sqrt{E}}\Sigma(2l + 1)P_l(\cos\vartheta)(e^{2i\delta_l} - 1).$$

The experiments show[5] that while the behavior in general is similar to the one indicated by this formula, the deviations are so great as to indicate an entirely different phenomenon not described by the theory. By using materials of different structures and varying in atomic number by one it was possible to obtain a scattering curve covering more or less completely the whole region of angles investigated (up to 10°). The results indicate that it is necessary to extend the theory in two directions: better approximation of the atomic field, and interaction between lattice and electron wave including the influence of surface or cross lattices.

[1] H. J. Yearian, J. D. Howe, *Rev. Sci. Inst.*, **7**, 26–30, 1936.
[2] K. Lark-Horovitz, J. D. Howe, and E. M. Purcell, *Rev. Sci. Inst.*, **6**, 401, 1935.
[3] K. Lark-Horovitz, H. J. Yearian, and J. D. Howe, *Phys. Rev.*, **48**, 101, 1935.
[4] K. Lark-Horovitz, H. J. Yearian, and J. D. Howe, *Phys. Rev.*, **47**, 331, 1935.
[5] H. J. Yearian and J. D. Howe, *Phys. Rev.*, **48**, 381, 1935.

WE reported in February 1935 on the completion of a Universal type of electron diffraction camera. The camera has been described since then in the *Review of Scientific Instruments* (Vol. 7, 26, January 1936). This apparatus allows investigation of electron scattering by substances in any desired state of aggregation: single crystals, solid powders, liquids or gases. It also allows intensity measurements by exposures taken in a definite ratio which can automatically be pre-selected.

The whole operation of the camera: changing plates and exposing them for any desired length of time, selecting of voltages—is all done automatically from a universal switch board.

The method of making thin films for the diffraction by solids has been extended by applying ammonium chloride as a new inorganic base for condensation of material.

In this way it was possible to show that the extra rings, as observed in electron diffraction, are actually due to organic layers formed on the surface of the material. If any such organic layer is excluded by producing the films on ammonium chloride and avoiding exposure to organic vapor, inner rings are never observed. If, on the other hand, such films are exposed to organic vapors, formation of the inner rings has been found. It seems, therefore, that the troublesome question in electron diffraction experiments regarding the existence of so-called forbidden rings, is now cleared up and solved by proving that these rings are due to organic impurities.

The method of making thin films was applied to the investigation of the scattering of electrons of varying energy. It has been pointed out before that electron diffraction allows observation of nucleus and surrounding electron cloud. If electrons of low energy are scattered by an atom of high atomic number, the distortion of the incoming electron wave in the potential field of the nucleus has to be taken into account. This means that the formula for scattering usually applied and leading to

$$F(\vartheta) = \frac{e^2}{4E} \frac{(Z - f)}{\sin^2 \vartheta/2}$$

cannot be used anymore, but one has to use the exact solution of the wave equation (written in Hartree units)

$$(\Delta + 2V + E)\psi = 0,$$

which leads to the following expression:

$$F(\vartheta) = \frac{-i}{2k}\sum(2l + 1)P_l(\cos\vartheta)(e^{2i\delta l} - 1).$$

We have pointed out in a former report that our results for the intensity of electron scattering by gold are markedly different from the ones obtained at much higher velocities by Rupp, and that we think this is due to an influence of the potential of the atoms.

In discussing these results with Dr. H. A. Bethe, he pointed out to us that probably these deviations should become still more pronounced if we would choose lower voltages.

The actual limit for voltage is given by the relative transparency of the different films and the necessary time for exposure. We found that electron velocities to about 20 kv. can easily be used. Below 20 kv. the sensitivity of the photographic plate decreases suddenly and exposure time becomes much longer. We have been able, however, to produce diffraction patterns at about 15 kv. As the first materials to be tried we have used gold and silver. The K excitation limit of gold is about 80 kv.; the K excitation limit of silver is about 25 kv. It is therefore easily possible to obtain diffraction patterns for gold films at electron energies well below the K excitation limit. This is also possible in the case of silver, and we have actually found much stronger deviations in about the same direction as the ones which we had observed originally with gold at 80 kv.

In the case of solid crystals the atom factor measures the scattering from the electrons of the different atoms in the crystal, and in this way it is possible to check the theoretical prediction. Since crystals reflect only under certain Bragg angles, it is impossible to obtain a complete scattering curve, but only points on this curve can be obtained in the different

regions. Therefore, we have made use of the following idea: if the electron scattering is actually influenced by the potential field of the atom only, then one would not expect a great deal of change if we compare the scattering power of atoms which are not more than one unit in atomic number apart. As such atoms we have chosen Pd 46, Ag 47, and Cd 48. In this way we obtain scattering under different angles since the different elements crystallize in different systems (Cd hexagonal. Ag, Pd cubic, but with different lattice constant), and therefore a more complete scattering curve has been obtained.

The scattering curves have been measured for electron velocities from 80 kv. down to 17 kv. At 80 kv. at a value far above the K excitation limit of the elements, the ordinary scattering formula represents the results adequately. In the lower voltages, strong deviations are observed which exhibit a marked periodicity in a region of not more than 10° of scattering angle.

Qualitatively this result seems to agree with the results obtained for the scattering of slow electrons (below 1 kv.); also in this case a periodic change of scattered intensity under different angles has been observed. This variation, however, extends over a wide range of angles and not over as small a range as we have mentioned above.

It seems, therefore, that we are dealing here with a new phenomenon which has not been observed before. This conclusion was confirmed by calculations of the theoretical scattering of 17 kv. electrons from gold and silver, carried out under the direction of Dr. Nordheim by Miss Fry. This calculation shows that also the exact solution of the wave equation, as given above, is not able to explain this effect.

One might consider first that this is due to the use of a Thomas-Fermi field for the atom, and that this should be properly replaced by a Hartree field. One can see, however, that since we are dealing with scattering at small angles, large values of l have to be considered (in our notation of the phase angle δ_l) and therefore, if such fluctuations occur one would expect that they should occur also in the phases δ_l

themselves. Since the Born approximation formula can be written in the following form also,

$$F(\vartheta) = \frac{i}{k} \sum (2l + 1) P_l(\cos \vartheta) \delta_l,$$

one would expect that such large fluctuations should occur in the phases themselves if using a Hartree field and that it would make a difference even for the approximate theory whether one uses a Thomas-Fermi or a Hartree field. We have plotted scattering curves using both fields wherever Hartree calculations are available, but no such fluctuations have been observed, and the curves are perfectly smooth.

We came, therefore, to the conclusion that the effect which we have observed can hardly be explained by a distortion of the electron wave by the free atom alone, but must be due also to the field of the atom in the crystal. It seems to be a type of dynamic scattering of electrons which does not produce new lines but a definite intensity change of the ordinarily observed Bragg reflections.

This hypothesis is being tested now by carrying out experiments on the scattering of electrons from molecular vapors using the same range of velocity as we have applied for the investigation of crystals. It is not possible to use scattering from free atoms in a monatomic vapor since for these small angles the ratio of inelastic to elastic scattering is so great as to even out the changes in relative scattering intensity under different angles for the elastic collisions.

Summarizing, we can say that it has been shown that while the kinematic theory of electron diffraction using a statistical distribution of electrons in the scattering atom, fits the experimental data for high energy electrons, this theory has to be replaced by a dynamic theory for electron energies small as compared with the K excitation limit of the scattering element.

Purdue University,
Physics Department.

EXPERIMENTS ON THE PRODUCTION OF HIGH VELOCITY IONS BY IMPULSE METHODS

J. W. BEAMS

EXPERIMENTS on the impulse methods of producing high velocity ions were undertaken with a two-fold purpose: first, if possible, to improve and make more practicable the technique already in use at the University of Virginia for accelerating ions by impulse methods to very high energies, and second, with this accomplished, to use the high velocity ions in nuclear studies.

As stipulated in the application for the grant of $2,500, it has been used for technical assistance. Starting in September, 1935, Dr. L. B. Snoddy has been paid $250 per month, or a sum of $2,000 to date. The remainder will be paid to Dr. Snoddy by the end of June. All equipment and supplies have been furnished by the University of Virginia, and this institution has also given a fellowship each to Dr. W. T. Ham, Jr., and Dr. H. Trotter, Jr., who have assisted with the problem.

The impulse method as we use it produces the high velocity ions by effectively moving the accelerating electrical field with the same speed as the ion. As a result the maximum velocity attainable, at least theoretically, depends upon the length of the tube through which the ion is made to move.

The principal new development required in this technique is obviously a suitable method of moving the electrical field along a tube with the same speed as the ion. In our work last year we used the well-known artificial transmission line to move the field and obtained protons with energies in excess of 2×10^6 electron volts. However, to obtain much higher energy protons than this, the tube became too long for the average laboratory room. (For heavy ions this limitation does not always exist.) Therefore we have set ourselves the task of devising a transmission line that will solve this difficulty. Some of the difficulties of constructing such a transmission line will become apparent when one realizes that

the wave front of the electrical impulse must not be appreciably flattened and that it must be timed with the ion (proton) beam to better than 10^{-9} sec. Even before we were able to study the behavior of the above type of line, it was necessary for us to improve our cold cathode gas focused cathode ray oscillograph until it would resolve approximately 10^{-9} sec. Furthermore, we now find it highly desirable to obtain still higher time precision and so an oscillograph embodying fundamentally new features has been designed and at the present time is almost ready for use.

It is our view that this impulse method should have its maximum value in the production of ions with energies in excess of that possible to produce by other methods. As a result, up to the present time, we have concerned ourselves entirely with the development of technique. A large number of different types of lines have been constructed and tried out on the tube. While as yet we have not completely succeeded in constructing a transmission line ideal for our purpose, we have very much improved our old one and believe that we have collected the information required to solve this problem. It is hoped that in the near future we shall be able to report in detail upon the solution of our problem in technique as well as its use, probably in some preliminary nuclear study.

University of Virginia,
April 15, 1936.

RESEARCH ON METEOR TRAINS

CHARLES P. OLIVIER

Work on this problem was started in September, 1935, on the arrival of Dr. C. H. Cleminshaw, whose subsequent time has been spent upon its prosecution. Largely through his efforts, though partly through those of the undersigned, both data and articles bearing upon the subject have been discovered in this country, and some have been sent to us from abroad. We have obtained many old records and had

access to original books and observations. A card catalogue has been made of 455 objects, with all the usable data digested thereupon, constituting far the most valuable list in existence.

As we are still expecting more data, especially from abroad, and as some rare publications remain unexamined, it has not seemed wise to make a definite attempt as yet to draw conclusions or to undertake laboratory experiments. We have gone far enough to know that our data will *not* confirm certain published conclusions. This makes us all the more anxious to obtain all data possible before stating our own. Also researches on meteor heights, carried on here simultaneously by others, are bringing up interesting conclusions, which we hope to tie in with the trains.

It was the original opinion of the undersigned that it would take two years properly to treat these problems, and the sequel has proved this opinion correct. A résumé of our present data is appended, with comparative figures for those used by former best-known investigators. The author of this note hopes most sincerely that in view of the progress so far made the Committee will see fit to renew the grant from the Penrose fund for one more year.

Summary of Data at Hand 1936, March 3		Data Used by Other Investigators
Total number of trains (data include at least the time, place, duration, and brief description)	455	
Trains for which the height of the producing meteor is known	100	
Trains of known height	71	13 (Trowbridge) 62 (Millman *)
Trains of known apparent drift	213	62 (Trowbridge) 94 (Kahlke)
True rates of drift computed from apparent drift by means of known height	35	19 (Denning *) 20 (Millman *)
Additional true rates of drift computed by means of assumed height	30	

Comparison of True Rates of Drift Computed from Known Height

Denning *	200 km./hr.
Millman *	Over 200 km./hr.
Flower Observatory	197 km./hr.

FLOWER OBSERVATORY,
UNIVERSITY OF PENNSYLVANIA.

* Details not published.

ISOTOPE ANALYSIS WITH THE MASS-SPECTROGRAPH

WALKER BLEAKNEY

The first installment of a grant from the American Philosophical Society was received October 1, 1935, for the purpose of furthering research in mass-spectra at Princeton. As was mentioned in the application, we especially needed financial aid to carry out large numbers of isotopic analyses of samples sent to us from other laboratories. I am happy to say that this help has enabled us to aid materially in three such research projects as well as to make considerable progress on some problems of our own.

A separation of the isotopes of argon by a diffusion process has been attempted by Professor Kruger and his students at the University of Illinois for certain optical and nuclear studies. The only feasible way of determining the separation achieved was by a positive ray analysis. Accordingly several samples of argon were forwarded to us and we completed the analyses quite satisfactorily. The results showed that no separation was attained. The important thing, however, was a conclusive result which enabled Professor Kruger to plan further research.

A much more successful experiment was carried out by Dr. D. F. Stedman of the National Research Council of Canada at Ottawa. By means of a large fractionating column he has been attempting to isolate the O^{18} isotope of oxygen in the form of water. This problem is regarded by chemists generally as of the utmost importance. We have spent considerable time in finding the O^{18} content of a long series of Stedman's samples, fifteen in all. Of the many attempts to fractionate the oxygen isotopes by different experimenters this work of Stedman has been the most successful. His best runs showed a concentration of the heavy oxygen isotope twice that found in nature. It seems reasonable therefore that this isotope may be prepared in pure form in the near future. Dr. Stedman considers the analysis made with the

mass-spectrograph of the greatest importance because it is the only reliable index of the progress of his work. We are pleased to be able to extend our facilities in the aid of this fruitful research. This work will be published by Dr. Stedman in the chemical journals, probably the *Canadian Journal of Research.*

Other attempts to fractionate the oxygen isotopes as well as those of carbon and nitrogen have been made by Professors Urey at Columbia and Taylor at Princeton with some success. In this connection we have been called upon to analyze several samples in an attempt to find a key reaction which would make the separation a practical one.

Turning to the work which primarily belongs to our own laboratory I am happy to report good progress along three different lines. One of my students, Mr. L. G. Smith, is making an exhaustive study of the products of ionization in methane, an understanding of which is not only of interest in itself but also throws light on the reported existence of helium and hydrogen of mass three because of the peculiar way in which hydrogen ions appear in methane. This work is about three quarters finished and is sure to lead to an important contribution in this field.

Evidence for the existence of an isotope of hydrogen of mass three has been found but at best it is rather inconclusive. In the last few months we have succeeded in setting up a set of diffusion pumps of the Hertz type which has shown a marked fractionating power on hydrogen and deuterium. We are now in a position to apply this apparatus to the separation of the third isotope of hydrogen and this experiment should give a conclusive test for the existence in nature of this interesting isotope.

As the problems associated with the lighter and simpler isotopes have approached solution, interest gradually shifts toward the heavier ones. In the field of mass-spectra this necessitates instruments of greater and greater resolving power. Hence we are making an effort to make the development of our technique and apparatus keep pace with the new problems which arise. The construction of a large magnet at

Princeton for another purpose makes possible with slight modifications the realization of a mass-spectrograph of exceedingly high resolving power. My assistant, Mr. J. A. Hipple, when not occupied with the requested analyses of outside samples has been building a small model of the proposed design. The results secured with this model have been extremely gratifying.

All of the work described above has been substantially aided by the generous grant from the Penrose fund of the American Philosophical Society. A full report on this work will be submitted at the end of the year.

Palmer Physical Laboratory,
Princeton University.

RESEARCHES IN THE PHOTOGRAPHIC INFRARED

RICHARD M. BADGER

In the report of December 1935 it was mentioned that there was some difficulty in deciding whether the $C - N \equiv C$ group in methyl isocyanide is strictly linear or whether it deviates slightly from this arrangement. The evidence on which this decision must be based is of the following nature. The possession of a three fold axis of symmetry by the methyl isocyanide molecule is dependent on the linearity of the group mentioned. In the case of non linearity the resultant lack of symmetry should have two effects upon the spectrum. One of these is a change in the selection rules, the other is the splitting of certain pairs of vibrations which are degenerate in the presence of the symmetry axis. The effect on one vibration of one of these pairs should be very marked since it should either greatly decrease in frequency or, in an extreme case, go over into a free rotation of two parts of the molecule with respect to each other.

We observed no evidence for non linearity of the group in either of these respects, but since it was uncertain how large the departure from symmetry must be to become evident in the spectrum it was decided to study some molecule in which there is a definite absence of the three fold axis, but in which

the asymmetry is not very great. Methyl alcohol appeared very suitable for this purpose since its lack of symmetry is due only to the light hydrogen atom which is located off the axis of the H_3CO group.

The methyl alcohol spectrum has proved to be very interesting. Several bands were observed in the photographic infrared, two of which, the harmonics of the $O - H$ vibration at λ9500 and λ7300, we have studied in detail under high dispersion since it was found possible to resolve a great deal of rotational fine structure. Each band was found to consist of between forty and fifty nearly equally spaced lines, with a few very intense features which we have called "Q" branches. On casual examination the bands resemble the parallel bands of methyl fluoride and one might be tempted to conclude that the methyl alcohol molecule is a symmetrical rotator. Closer inspection reveals evidence of lack of symmetry since there are present certain weak "satellite" branches in the bands which are not found in the methyl fluoride bands. These additional branches we attribute to the possibility of a more or less free rotation of the hydroxyl hydrogen about the axis of the H_3CO group. From the observed structure of the bands it seems permissible to conclude that this rotation is not entirely free but on the other hand that the hydrogen atom is not strongly bound in any definite orientation with respect to the remainder of the molecule.

The investigations on methyl alcohol vapor have been described in detail in a paper which has been submitted to the *Journal of Chemical Physics*.

The theory of those molecules in which internal rotation is possible is at present very incompletely developed, which makes a complete interpretation of the methyl alcohol spectrum impossible, until further work is done. Since this backwardness in the theory is no doubt due to lack of experimental information on the "torsion rotator-vibrator" type of molecule it appeared of interest to study the spectra of a series of such molecules. Consequently we have examined the following substances in the vapor state: ethyl, isopropyl,

allyl, normal and tertiary butyl alcohols, and phenol and orthochlor phenol.

Some of these substances had previously been studied by Wulf and Liddel (*Journal of the American Chemical Society*, **57**, 1464, 1935) in carbon tetrachloride solution, but in the liquid condition many of the interesting features of the spectra are blurred out. In their study of the second harmonic of the O — H vibration these observers found only one maximum in each case except orthochlor phenol.

We have studied the third harmonic of the O — H vibration in the vapor state and have found in most cases a considerably more complex structure. Although no rotational structure in the ordinary sense could be resolved it was observed that in several cases the bands consist of two or more components which evidently arise either from the possibility of several more or less stable orientations of the hydroxyl hydrogen or from a nearly free rotation. The experimental side of this investigation has been practically completed but there is still considerable to be done in the interpretation of the results. We hope by a comparison of the various bands to be able to arrive at a qualitative interpretation of their structure. Several interesting facts have already come to light.

In particular it is of interest to note how the O — H frequency shifts from one alcohol to another. This frequency is the highest in methyl alcohol of all compounds we have studied except water. As each hydrogen of the methyl group is replaced by a methyl group the frequency is lowered by a more or less constant amount which may perhaps indicate a very slight weakening of the O — H bond. The frequency shift cannot be due entirely or even largely to a mass effect since replacement of hydrogens not attached to the carbinol carbon does not have much effect. For example, ethyl alcohol and normal butyl alcohol do not differ very much in the O — H frequency.

The types of band observed in the different cases differ considerably. In some cases a very definite Q branch appears, in others it is weak or definitely absent. The type of structure

appears to depend on the orientation of the O — H bond with respect to the principal moments of inertia of the molecule.

In connection with the alcohols we have studied another substance which seems of particular interest. In the vapor of nitric acid we have observed strong bands at $\lambda 9832$ and $\lambda 7455$ which we may quite definitely identify as two harmonics of the O — H frequency. The band at $\lambda 9832$ has an especially interesting appearance as it has the sharpest and most intense Q branch which we have ever observed. Our work shows that the hydrogen atom in the nitric acid molecule is definitely attached to one of the oxygen atoms and certain previously observed facts appear to indicate that this oxygen atom is bonded to the nitrogen atom in a different manner from the remaining two.

When the interpretation of the work described is completed it will be published in the *Journal of Chemical Physics*. A complete understanding of the results will of course not be possible until the theory is further developed. This is at present receiving attention in several quarters and it is hoped that with the new data which we have made available more rapid progress may be made. The results which one may expect from the complete interpretation are, in particular, knowledge of the interaction of the hydroxyl hydrogen with other parts of the alcohol molecule, and the magnitude of the "potential humps" which are passed through in a complete rotation of this atom. This information is very necessary for the theoretical calculation of the specific heats and entropies of the alcohols and may also be expected to throw some light on the reactivities of the different alcohols.

The investigation of the new type of spectrum above described has proved so interesting and appears to be so profitable that it is planned to extend it to other types of "torsion oscillator rotator," in particular to the amines.

It is wished again to express appreciation to the American Philosophical Society for the grant from the Penrose Fund which has made the investigations possible.

Gates Chemical Laboratory,
California Institute of Technology,
Pasadena,
June 3, 1936.

THE OFFSPRING OF A TRIPLOID SPOROPHYTE [1]

ELIZABETH MACKAY AND CHARLES E. ALLEN

(Read April 23, 1936)

ABSTRACT

A diploid female plant ($2A + 2X$) of *Sphærocarpos Donnellii* mated with haploid males ($A + Y$) produces triploid sporophytes most of whose spores are arranged in normal-appearing tetrads. In the great majority of cases these spores have failed to germinate.

However, an unusually large proportion of spores from one family of triploid sporophytes germinated. Most of the resultant gametophytes grew feebly and died while still very small. Among these gametophytes, a few, coming from spores of dyads, were apparently female; probably they were triploid ($3A + 2X + Y$), possibly intersexes. Among the gametophytes derived from spores of tetrads, the majority were female or apparently female. Seven have survived to supply material for the present study.

Of these seven gametophytes one is male, with 16 ($2A + 2Y$) chromosomes; six are female, with 15 ($2A + X$) chromosomes.

THE OCCURRENCE of diploid gametophytes of *Sphærocarpos Donnellii* Aust. has been several times reported (1–4). Diplonts of the most frequent type yet known in this species arise from the spores of dyads which, usually rarely, but relatively frequently in the sporophytic offspring of some matings, appear instead of tetrads. Diplonts of this class (1, 3, 4) have the chromosomal endowment $2A + X + Y$[2] in contrast with ordinary haplonts which, if male, possess $A + Y$, or, if female, $A + X$. The diplonts in question ($2A + X + Y$) are female in appearance and to some extent in function, but betray the possession of male potentialities by the occasional production of intersexual organs.

In addition to such diploid intersexes, one diploid male clone with $2A + 2Y$ chromosomes has previously been observed (3), as has also one diploid female clone with $2A + 2X$ (2); the latter was the maternal ancestor of the family to be considered in the present paper.

[1] Study carried on with the aid of grants from the Penrose Fund of the American Philosophical Society and from the Wisconsin Alumni Research Foundation.

[2] "A" throughout this paper refers to a single complete set of seven autosomes; "X" and "Y" indicate the respective sex chromosomes.

Since the eggs (or some of the eggs) of a diploid intersex as well as those of the diploid female just mentioned can be fertilized by haploid antherozoids, the result in either case is the production of triploid sporophytes. Such sporophytes in general bear apparently normal spores which in the strains that have been studied remain adherent, like those of diploid sporophytes of related races, usually in tetrads but occasionally in dyads. In an occasional triploid sporophyte, however, the spore complexes (dyads and tetrads) are variable in size and more or less irregular in form.

The great majority of the spores of triploid sporophytes have thus far failed to germinate. From eight sporophytes produced by six matings of diploid intersexes with haploid males, seven dyads, 257 tetrads, and three small bodies (possibly monads) have been sown. Germinations have resulted, apart from one doubtful case, only of the spores of one tetrad. Of the offspring of the tetrad in question, as already reported (3), one is male (with A + Y chromosomes), one an intersex (with 2A + X + Y).

Better results (2) have been obtained in the germination of the spores from sporophytes produced by the diploid female (30.1004) mated with a haploid male (23.5058). However, the sowing of spores from four sister sporophytes and from 16 sporophytes produced by 10 other matings of this female, involving 130 dyads, 461 tetrads, and 19 triads or spore complexes of questionable nature, has yielded only one certain and two doubtful germinations. From the one family of sporophytes the spores of which germinated in numbers, three dyads produced five gametophytes, of which three were apparently females (in the light of present knowledge, very possibly triploid intersexes) and two died before producing sex organs. The spores of 25 tetrads (all from one sporophyte) produced 60 females, 10 males, and 18 gametophytes that died before their sex was determinable. It was the preponderance of females in this family, together with the production of three or four instead of but two apparent females from each of at least 11 of the tetrads, which gave the

first clue to the unusual chromosomal endowment of the maternal clone. Even among the gametophytes of the family which lived to produce sex organs, many grew very slowly and the great majority died comparatively early.

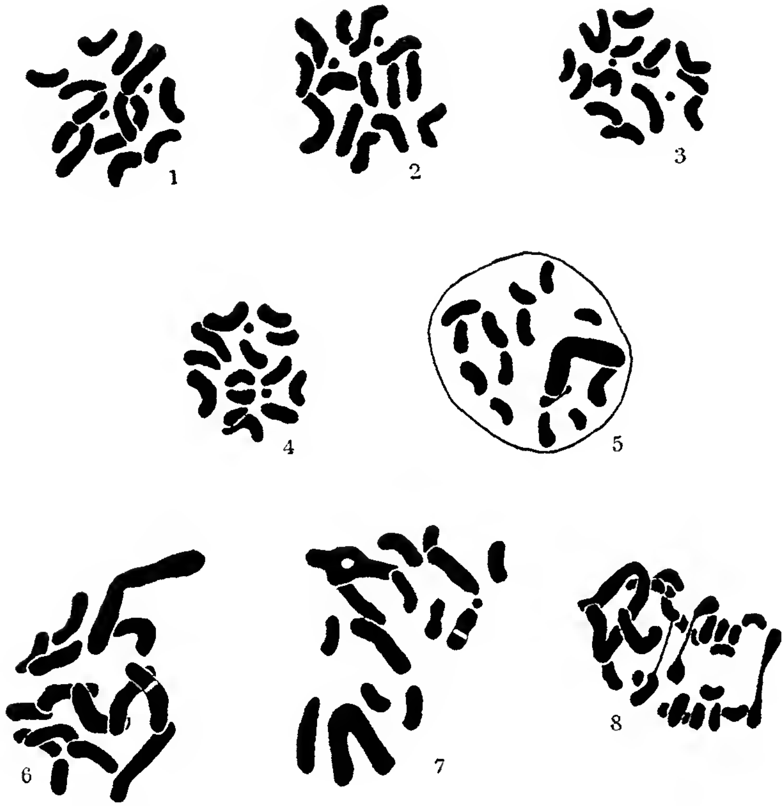
The present study is an attempt to determine the chromosome complements of such clones of this family as still survive. Such determinations may be expected to throw some light upon the course of chromosome-segregation in the meiotic divisions which produced the spore nuclei; and to show which are viable of the many chromosome combinations that may conceivably result from meiosis in a triplont.

Eight of these clones, all from spores of tetrads, survived long enough to furnish cytological material. Of these, seven were female, one was male. One female died after the study was begun but before it had yielded satisfactory chromosome figures. Of those which still survive, only three, the male (32.77) and two females (32.25 and 32.65), have proved at all vigorous. The others have grown slowly and have been kept alive only by unusual care.

Fixatives used were Flemming's medium, Carnoy's alcohol-acetic, and Karpechenko's and Sax's modifications of Navashin's mixture. Preparations were stained in iron-alum hæmatoxylin following Flemming and Carnoy fixations, or with crystal violet-iodine-picric acid following the Navashin combinations.

Counts of chromosomes in division figures in the surviving clones have shown that the one male has $2A + 2Y$ chromosomes (Figs. 1–4), and that each of the six females has $2A + X$ (Figs. 5–23). While the objective determination of the precise chromosome number in such a diplont is difficult because of the crowding of the chromosomes within a very small cell, and while consequently some division stages examined are capable of interpretation in terms of numbers larger or smaller by one than those here given, these numbers are reported with considerable confidence. In each clone some stages (only one from clone 32.62) were obtained which made possible an unambiguous determination.

The spore tetrad which gave rise to the male clone 32.77 (Figs. 1–4) produced in addition one other male and two females, all of which grew slowly and died while very small. A haphazard distribution of the sex chromosomes (2X and 1Y) present in the triploid sporophytic parent might be expected

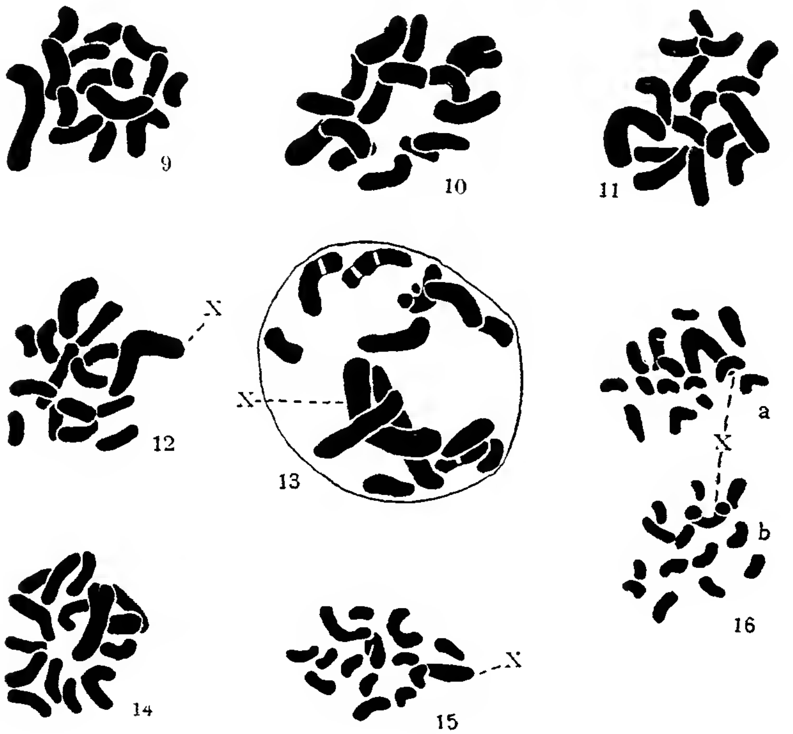


Figs. 1–4. Polar views of androgonial equatorial plates, male clone 32.77; 2A + 2Y chromosomes. Figs. 5–8. Female clone 32.22 (2A + X): Figs. 5, 6, prophases; Fig. 7, late prophase; one satellite chromosome; Fig. 8, meta-anaphase in lateral view; not all autosomes visible; lagging X. All × c. 3600.

to endow the spores and resultant gametophytes with either one Y, one X, two X's, or one X plus one Y. The presence of two Y's in a male offspring is therefore unexpected, although in the present instance unquestionable. Non-disjunction of the daughter Y chromosomes in a premeiotic

division is a possible explanation. It is noteworthy that the only other diploid male clone yet reported (3) had exactly the same chromosome complement.

Of the females of this family, clones 32.22 (Figs. 5–8) and 32.24 (Figs. 9–12) came from spores of a single tetrad. The other spores of this tetrad produced one clone determined



Figs. 9–12. Female clone 32.24 (2A + X); prophases. Figs. 13–16. Female clone 32.25 (2A + X): Fig. 13, prophase; one satellite chromosome; Fig. 14, prophase; Figs. 15, 16, anaphases in approximate polar view; both sister groups (*a*, *b*) shown in Fig. 16. All × c. 3600.

as female which died while small, and a fourth which perished before forming sex organs. Since each of the surviving tetrad sibs possesses two sets of autosomes and one X, it is not unlikely that the other two had each one set of autosomes plus one X and one Y. Clones of the latter constitution would be expected to be intersexual but female in external appearance;

the presence of two sex chromosomes with but one set of autosomes might render them but feebly viable.

The other four surviving female clones represent individual spores of four distinct tetrads. Clone 32.25 (Figs. 13–16)

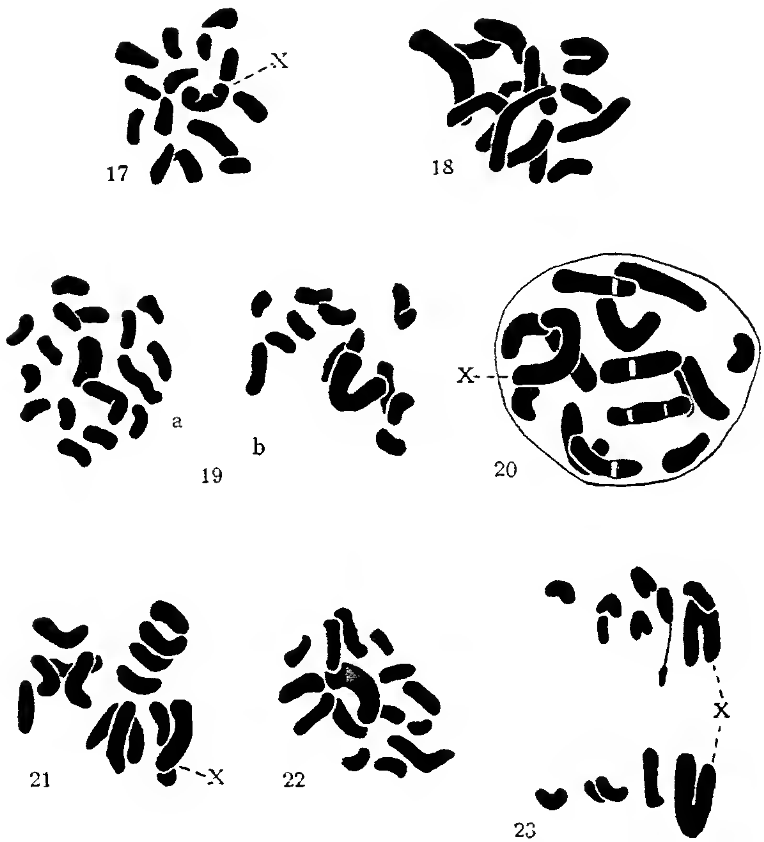


Fig. 17. Polar view of anaphase group, female clone 32.62 (2A + X). Figs. 18, 19. Female clone 32.65 (2A + X): Fig. 18, late prophase; Fig. 19, polar view of sister anaphase groups; one (*a*) with 16 autosomes and one X, the other (*b*) with 12 autosomes and one X. Figs. 20–23 Female clone 32.114 (2A + X): Figs. 20–22, prophases; Fig. 23, anaphase in lateral view; not all autosomes visible. All × c. 3600.

was one of four tetrad sibs, all determined as female; two of these in all probability, had they been studied in section, would have betrayed an intersexual tendency by the presence of sex organs of intermediate type.

Clone 32.62 (Fig. 17) was one of two from a tetrad, both determined as female. Division stages are rare in material examined from this clone, and figure 17 represents the only one in which an accurate chromosome count was possible. This figure, however, seems conclusive.

Clone 32.65 also has yielded few mitotic stages; figures 18 and 19 were the clearest. The former shows 14 autosomes and one X. Figure 19 presents two sister anaphase groups, one (*a*) with 16 autosomes and an X, the other (*b*) with 12 autosomes and an X—a clear case of non-disjunction. The other three clones from the same spore tetrad as 32.65 were apparently female; probably two of these were intersexes.

Clone 32.114 (Figs. 20–23) was one of two females derived from a tetrad. One X and 14 autosomes appear in figures 21 and 22. In figure 20, representing a median prophase, some of the autosomes are nearly as large as the X; but the total number of 15 is unmistakable. The difficulty in distinguishing the X chromosome at such stages results from the fact that, as Tinney (6) has shown, the allosome condenses to its final size more quickly than do the autosomes.

Although the preparation of material in this study has been primarily for the purpose of determining chromosome numbers, some of the figures illustrate certain features of chromosome structure. In a number of instances (Figs. 6, 7, 13, 20), autosomes show achromatic regions at the levels at which more commonly constrictions are apparent. In some cases the X chromosome shows a constriction at the point of spindle-fiber attachment (*e.g.*, Figs. 5, 6). In metaphases and early anaphases (Fig. 8) the X manifests its characteristic tendency to lag behind the autosomes in the poleward movement. In two instances (Figs. 7, 13) one chromosome apparently bearing a satellite was observed. This may correspond to the satellite chromosome described by Lorbeer (5).

The error most likely to occur in determining chromosome complements in *Sphærocarpos* concerns the Y chromosome which because of its minuteness may be overlapped or other-

wise obscured. Thus in various division stages seen in male clone 32.77 only one Y can be recognized; but others (Figs. 1–4) show conclusively that two Y's are present. That a Y was not overlooked in some of the female clones here described is confirmed by the fact that no intersexual organs were found in any instance, although a careful search was made for them. Previous work (1, 3) has shown that such organs occur in diploid clones which, although externally apparently female, possess both an X and a Y.

Nothing final can be said at present regarding the fertility of the clones of this family. The amount of material of any of them available for mating previous to the present season has been small. Three matings have been made between the maternal clone 30.1004 and its male offspring 32.77. No sporophytes were produced. The same male clone has likewise proved sterile in two matings with its sib 32.25, in one mating with sib 32.65, and in two matings with diploid intersexes. Female clone 32.24 in a mating with a haploid male produced one sporophyte. Female clone 32.25, similarly mated, gave rise to two sporophytes. The spore complexes borne by the latter two sporophytes, sown, failed to germinate.

On the analogy of known occurrences in angiosperms, it is to be expected that meiosis in a triploid sporophyte will result in the production of a variable number of chromosomes ranging at least from the haploid to the diploid number. Considering autosomes alone, this would imply the formation of spores with from seven to 14. It is perhaps not accidental that all *Sphærocarpos* gametophytes derived from triploid sporophytes whose chromosome complements it has hitherto been possible to determine have either, as in one case previously reported (3), seven—the haploid number—or, in eight cases including one previously reported, 14—the diploid number of autosomes. The suggestion is obvious that hypo- and hyperhaploid, hypo- and hyperdiploid autosome combinations are non-viable or at best feebly viable.

The large proportion of germinations of spores of the sporophyte which gave rise to the family here in question

affords a striking contrast to the very rare germination of spores from all other triploid sporophytes of whatever ancestry which have been tested. Possibly in this particular sporophyte the meiotic divisions proceeded in such fashion as to give rise predominantly to complete haploid and diploid autosome complements.

It is true that in the clones here discussed, visual evidence does not demonstrate that each complement of 14 chromosomes represents an exact duplication of the typical set of seven. Differences between individual autosomes are in general too slight for such determination. However, the occurrence of 14 autosomes in so many instances, and the lack of numbers intermediate between seven and 14, render the assumption alone plausible that in a complement of 14 each of a set of seven is twice represented.

As to the sex chromosomes, it is shown that two sets of autosomes plus one X constitute a viable combination (hypodiploid in terms of the whole chromosome complement). Oddly enough, the maternal complement of 2A + 2X seems not to have been duplicated in any of the offspring. As yet, while in work to date two clones have appeared with a complement of 2A + 2Y, and numerous clones with 2A + X + Y, there is no evidence of the viability of the combination of two sets of autosomes plus one Y.

Summary

A diploid female plant (2A + 2X) of *Sphærocarpos Donnellii* mated with haploid males (A + Y) produces triploid sporophytes most of whose spores are arranged in normal-appearing tetrads. In the great majority of cases these spores have failed to germinate.

However, an unusually large proportion of spores from one family of triploid sporophytes germinated. Most of the resultant gametophytes grew feebly and died while still very small. Among these gametophytes, a few, coming from spores of dyads, were apparently female; presumably they were triploid (3A + 2X + Y), possibly intersexes. Among

the gametophytes derived from spores of tetrads, the majority were female or apparently female. Seven have survived to supply material for the present study.

Of these seven gametophytes one is male, with 16 (2A + 2Y) chromosomes; six are female, with 15 (2A + X) chromosomes.

Chromosome complements thus far observed in viable gametophytes of this species are: *Female*, A + X, 2A + X, 2A + 2X; *Intersexual*, 2A + X + Y; *Male*, A + Y, 2A + 2Y.

Chromosome complements so far known in viable sporophytes (cytologically observed only in the first class cited) are: 2A + X + Y, 3A + X + Y, 3A + X + 2Y, 3A + 2X + Y[1].

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[1] Since this paper has been in press, sporophytes (mostly in small numbers) have resulted from two matings of clone 32.22, one of clone 32.24, and three of clone 32.25, all with haploid males; and from two matings involving the diploid male 32.77, one with its diploid female sib 32.65, and one with another diploid female (35.2201) tentatively determined as having 2A + X chromosomes. The sporophytes produced in the two matings last mentioned are therefore *tetraploid*, having chromosome complements of 4A + X + 2Y.

OBSERVATIONS ON THE UPPER SIWALIK FORMATION AND LATER PLEISTOCENE DEPOSITS IN INDIA

H. DE TERRA AND P. TEILHARD DE CHARDIN

CONTENTS

ABSTRACT

New field studies, carried out last year, lead the authors to a more concise classification of Pleistocene sequences in India. The "Upper Siwaliks" are considered to be of Pleistocene age throughout with the uppermost stage being as young as the second glacial advance in the adjoining Himalaya. The "Boulder Conglomerate" stage witnessed the arrival of Ancient Man whose Paleolithic industries were discovered in NW-India as well as in the fossiliferous Narbadda formation in Central India. The Siwalik history closes during the middle Pleistocene and is followed by alternating erosion and deposition of lœssic beds beneath which a younger Paleolithic industry was found. The geological sections described permit of recognising three to four phases of mountain making since the close of the Pliocene period.

A. INTRODUCTION

TO ANYONE who studies closely the various publications and fossil collections of the Siwalik formations of northern India, it becomes evident that the boundaries, the paleontological and tectonic characters of the Upper Siwalik and later formations are rather imperfectly known. Therefore a closer

field study of their stratigraphy was needed, not only in order to clarify questions still pending but also to build a stratigraphic foundation on which the dating of young crustal movements and of early human cultures in Northwest India could be based.

Pilgrim's [1] stratigraphic terms "Tatrot," "Pinjaur" and "Boulder Conglomerate" are universally used to designate the three stages of the Upper Siwalik formation, but the meaning of each term remained indefinite under the assumption that the three divisions make a faunistically and stratigraphically uniform group. This view had found its most pregnant expression in Van Vleck Anderson's [2] statement that in the "Nimadric system" (the post-Eocene freshwater formations of the Himalayan foothills) there appears to be "comformable gradation throughout."

As a result of observations made lately by the authors it seems on the contrary:

(1) that the older Upper Siwaliks (Tatrot-Pinjaur) represent a perfectly individual unit generally sharply separated from the Dhok Pathan stage below and from the Boulder Conglomerate stage above, and

(2) that this separation being made clear, the faunistic groups corresponding to the Middle and Upper Siwaliks become appreciably more distinct.

In the following we shall describe several type sections, studied by ourselves, in which the relationships between the three stratigraphic elements, namely the Middle Siwaliks, the older Upper Siwaliks and the Boulder Conglomerate are especially clear and decisive. In view of the fact that these sections comprise also post-Siwalik formations it seemed advisable to make brief references to them. From the facts exposed our conclusions will follow naturally.

We are under great obligation to the American Philosophical Society at Philadelphia for having supported our work which enabled us to carry out a joint research within a

[1] G. E. Pilgrim, Records Geol. Survey India; 1910 et seq.
[2] R. Van Vleck Anderson, *Bull. Geol. Soc. Am.*, 38, p. 674.

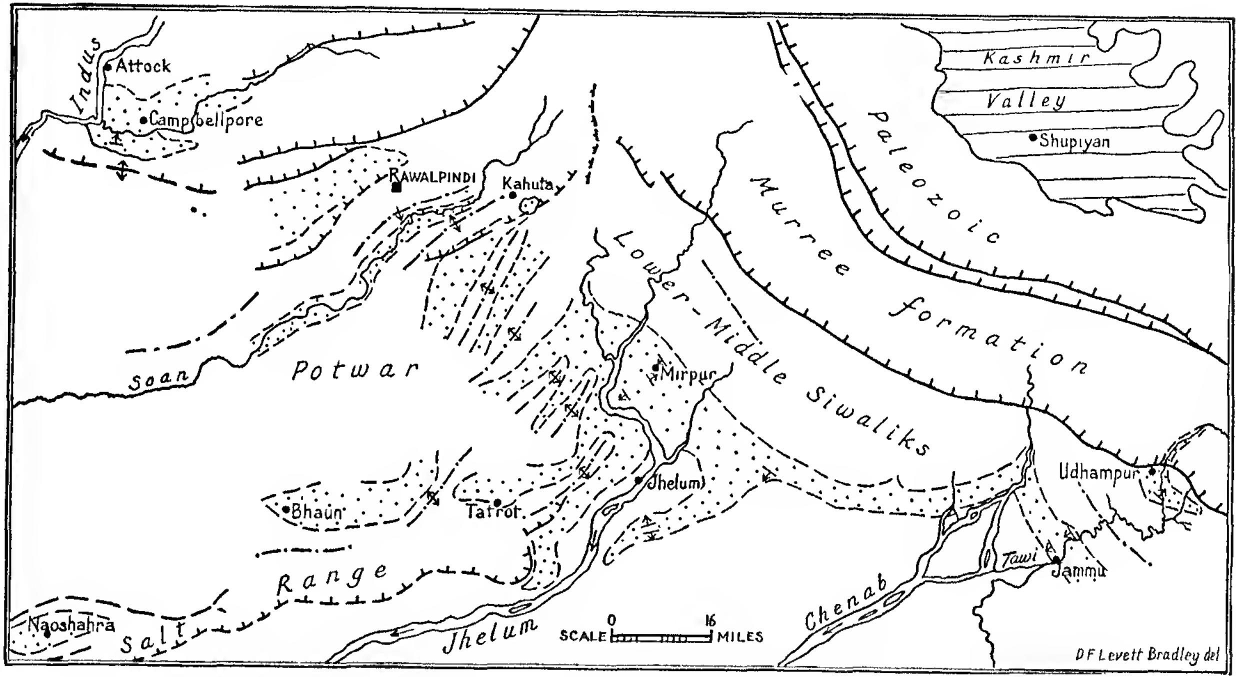

FIG. 1. Sketch map showing structural pattern and distribution of Upper Siwalik beds in the NW-Punjab

Upper Siwaliks = stippled; Kashmir Pleistocene = ruled; major Pliocene anticlines = broken line with dots; major overthrusts = solid or broken lines with right angle intervals.

more extensive program of geological and prehistorical studies in India. We also feel greatly obliged for the support of the Carnegie Institution in Washington and for the encouragement which Dr. John C. Merriam gave to the entire undertaking. The coöperation of the Geological Survey of India and of that of the American Museum of Natural History is most sincerely appreciated. In particular we thank Dr. Edwin H. Colbert who already determined a larger portion of Upper Siwalik fossils collected by us.

B. Observations on Type Sections through Upper Siwalik Formations

I. Indus and Potwar Areas

1. Campbellpore

The basin of Campbellpore lies southeast of Attock in a dissected portion of the Punjab plains which is here bordered in the east by the Indus river, towards the south by the Kala Chitta ridge, and in the west by the Haro river, a tributary of the Indus. The surface lies some 1200 feet above sea-level, forming a depression which is flanked in the north by thrusted Paleozoic rocks, and in the south by an anticline, built of Eocene limestone and Mesozoic formations. The basin is at least nine miles broad and over 15 miles long in a west-easterly direction.

The basin sediments are exceptionally well exposed as indicated in Fig. 2. This section begins near Choi, in the vicinity of the road to Basal and extends across the NNW-SSE strike of the formation to the Haro river and beyond over a distance of five miles. In the centre of the basin appears a horizontal gravel cap, some 8–20 feet thick, which contains large erratic blocks and glacially facetted boulders. This gravel is a fluvio-glacial outwash deposit which can be traced back to the mountain front where the Pleistocene glaciations have recently been investigated by de Terra and Paterson. Previously Wynne[1] had interpreted this boulder gravel as a

[1] *Rec. Geol. Survey of India*, 13, 1880.

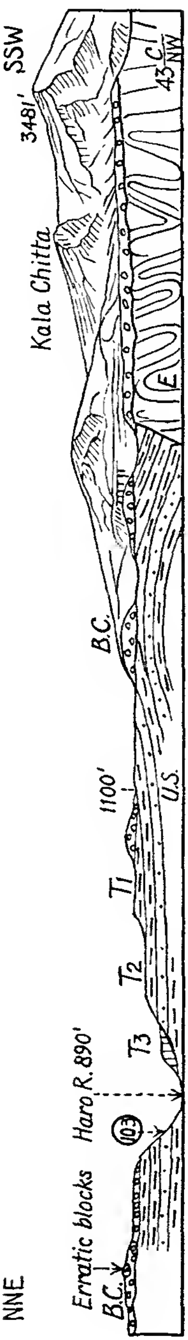

Fig. 2. General cross-section through Campbellpore basin

B. C. = Boulder Conglomerate; U. S. = older Upper Siwaliks; E = Eocene; $T_1 - T_6$ = Pleistocene terraces; total length 5 miles (all sections bear index mark of topographic sheets at right hand corner).

glacial deposit. Northeast of the Haro river this gravel continues up the slope of the Kala Chitta where it finally merges with a large fan composed of Eocene limestone blocks. This fan reveals a period of intense denudation in the ridge which is doubtless responsible for its accumulation. The fan merges along the Haro river with the fluvio-glacial outwash in which we recognise the "Boulder Conglomerate" of Upper Siwalik time.

Underneath the gravel lie the basin sediments proper. They are gently folded and apparently faulted against Eocene limestone. The upper portion of this sequence is shown in Fig. 3. The orange clays and whitish-grey sandstones in

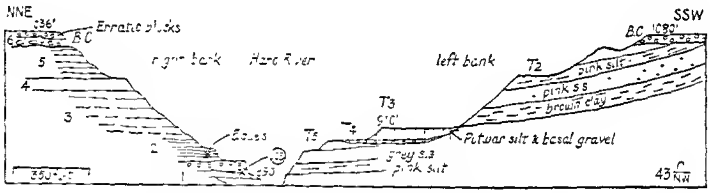

FIG. 3. Combined section through Campbellpore basin along Haro river
1 = grey pebbly s.s. and clay, 16 ft; 2 = laminated greenish-brown silt and s.s., 12 ft; 3 = orange silt and concretionary caly, 10 ft.; 4 = grey s.s., 8–10 ft.; 5 = light orange clay, 20 ft. (dip exaggerated)

this section resemble the Dhok Pathan rocks of Middle Siwalik age for which they might easily be mistaken at first glance. Luckily we found at the base of this upper group numerous fossils which prove its Upper Siwalik age. In the greenish silt was found a palate of horse (*Equus*), and in the underlying soft grey and sandy layers (at locality 103) we discovered a bone pocket, crowded with mammal bones belonging mainly to the following forms: *Stegodon*, *Bubalus* (sharply trihedral horn-cores), deer, *Hyæna*, *Felis*, *Machairodus*, *Mustela*, *Viverra*, *Boselaphus*, strepsiceros antelope, *Sus*, all of typical Pleistocene affinities.

In the southwestern continuation of the section appear conformably brown clay, pink silt and grey or pinkish sandstone in alternating fashion, and partly cross-bedded, which abruptly border the Eocene limestone in a thick series of

bluish-grey silts. At places the brown clay contains indistinct plant remains, at others it is laminated. Both these features cause it to resemble the "lower Karewa" beds of Kashmir, which belong to the first interglacial period. In this region the beds form a flat anticline which is unconformably overlain by Boulder Conglomerate. The thickness of these beds must amount to some 500 feet.

It is in this connection interesting to note that Mr. T. Morris recently found a similar formation with similar fossils near Pezu in the Northwest Frontier Province. Here the Middle Siwaliks are present while at Cambpellpore no Dhok Pathan beds appear.

Noteworthy in this section are certain gravels and overlying yellow silts which rest against the Boulder Conglomerate, and at the same time fill the dissected relief within the basin where they form terraces along the Haro river. Such younger deposits are widespread in the Potwar region, some 40 miles east of Campbellpore, and they shall henceforth be called "Potwar silt."

2. Soan Valley near Rawalpindi

The Soan river is a tributary of the Indus which flows from north to south across the Potwar area near Rawalpindi. Its valley occupies a syncline in Siwalik formations which strikes northeastward in conformity with the syntaxis of Himalayan folds as outlined by Wadia.[1]

A few miles southeast of Rawalpindi, on the right bank of the Soan river, the Boulder Conglomerate is represented by a faintly tilted series of hard limestone conglomerates and alternating beds of pink sand, silt and clay which form high terrace remnants above the level of the Potwar plain (Fig. 4). This series overlies here unconformably the levelled edges of Murree sandstone and of Middle Siwalik rocks, a relationship which can clearly be studied on the left bank opposite Kund. As one proceeds further southeast the conglomerate changes, it becomes looser and is mainly composed of various quartzite

[1] D. N. Wadia, *Geol., Mining and Met. Soc. India, Quart. Jour.*, 4, 1932.

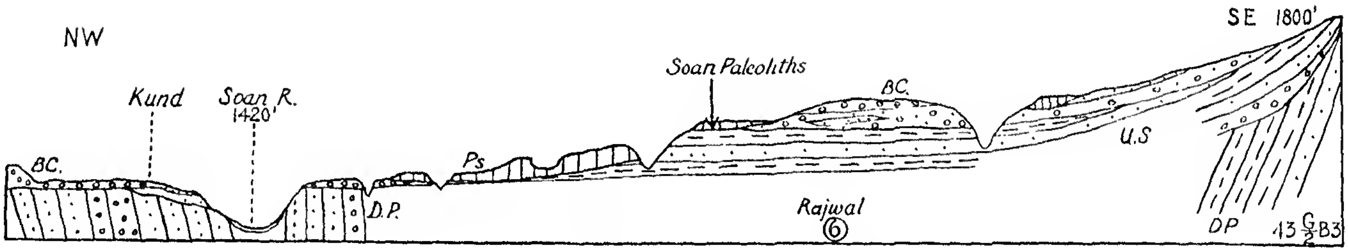

FIG. 4. Section through Soan basin near Rawalpindi

D. P. = Dhok Pathan (late Pliocene) s.s. and conglomerates; Ps = Potwar silt; Scale: 1″ = ½ mile, height 10 ×.

pebbles with a transition to pink and grey sands and silt. This change in the pebble composition is no doubt due to a different supply of gravels, part of which seem to be derived from the conglomerates of the underlying Dhok Pathan rocks. A typical sequence is to be found at Rajwal where the cliffs expose a thickness of 110 feet. The intervening country between this place and the Soan river displays a deeply dissected series of light pink and yellow clay obviously representing, in parts at least, the Potwar silt. Early Paleolithic tools were found in the highest conglomerate layers, while a Middle Paleolithic industry in unworn state was frequently met with at the base of the Potwar silt.

Here again the Boulder Conglomerate consists of two facies, one with limestone gravels, the other with quartzite pebbles. The latter is bound to the Soan valley proper, whereas the other is traceable to an Eocene limestone ridge on the Himalayan side of the Potwar plain. Some 15 miles north of this section the limestone conglomerate contains large boulders and it seems to continue into the formerly glaciated valleys of the adjoining Pir Panjal range.

Beneath the Boulder Conglomerate lies a thick series of grey-brownish sands, red clay and layers of harder conglomerate which clearly belong to the older Upper Siwaliks. In the basal conglomeratic sandstone were found a few rolled fragments of mammal bones which, although they do not permit of identification, nevertheless show the state of fossilisation characteristic for the Upper Siwalik stage. The sombre colours and the loose consistency of these beds contrast sharply with the hard, brightly coloured rocks of Dhok Pathan age. At the base appears a thick brown and sandy conglomerate which adjusts its dip, like the overlying beds, to that of the Middle Siwalik group.

The section fig. 4 suggests subsidence of the Soan basin in three stages:

1. Subsequent to intense folding of older Siwalik rocks sinking and deposition of Upper Siwaliks.

2. Renewed folding with both Middle and older Upper Siwaliks tilted and deposition of Boulder Conglomerate.

3. Further tilting of all three formations.

II. Himalayan Foothills between Kahuta and Jammu

This region extends through the foothills of the Pir Panjal range east of Rawalpindi towards the outlet of the Tawi river at Jammu. Physiographically it presents low strike ridges and hills which rise 2000 to 3000 feet above the Punjab plain. Structurally it is characterised by the proximity to Himalayan overthrusts which give evidence of progressive crustal movements of Tertiary and Pleistocene age which appear to be directed against the Salt Range area in the Southwest.

3. Kahuta

T. T. Paterson, geological associate of the expedition, drew our attention to a small basin of Pleistocene beds near Kahuta which lies about 20 miles east of Rawalpindi. It makes a syncline in Middle Siwalik rocks which form boat-shaped strike ridges due to the pitching of fold axis in a southwesterly direction. The shape of the basin is sub-oval, its dimensions being $2\frac{1}{4}$ miles wide and some 3 miles long.

Fig. 5. General section through Kahuta basin
Total length ca. $3\frac{1}{2}$ miles.

Section Fig. 5 begins in the vicinity of Gurhat hamlet and is drawn across the basin towards Gagari. At the former place an exposure shows the contact between steeply inclined hard Dhok Pathan sandstones and a soft grey conglomerate (15 feet thick) which is overlain by a series of grey soft sandstones, brown and pink clay and silt. The quick flattening of the dip and the rapid thinning out of the beds

along the contact indicate drag-faulting due, no doubt, to "settling" of the softer rock material in the more rigid frame of Dhok Pathan rocks. A similar relationship was found along the road to Kahuta where the disturbed condition of the beds is very conspicuous. In this basin filling we did not find any fossils, yet its lithological composition is in all respects so similar to that of the Upper Siwaliks that it can only be referred to this group.

Basin filling and older beds are covered by patches of loose quartzite gravel. Its widespread occurrence on all neighbouring ridges suggests that it belongs to a large fan which may have been deposited by an ancestral Jhelum stream the present course of which is found only a few miles distant. In this coarse gravel we recognise the Boulder Conglomerate. The Potwar silt rests against the slope of the conglomerate terrace.

4. Mirpur

This basin also was pointed out to us by Mr. Paterson as representing an unusually complete sequence of Upper Siwaliks and disturbed Boulder Conglomerates.

Figure 6 gives a general section, showing north of the Jhelum river an anticline in pink and brown silt and sandstones. Towards Mirpur this asymmetrical fold is overlain

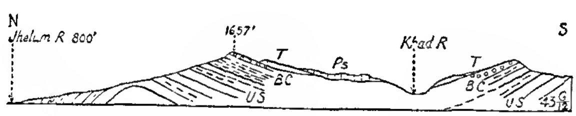

FIG. 6. Schematic section through Mirpur basin
T = high terrace; total length ca. 14 miles.

by pink sandy conglomerates with interbedded loose sandy layers which beds lie apparently conformable on the older group. This contact however must be in the nature of a disconformity, for the Boulder Conglomerate spreads widely across denuded Middle Siwalik rocks with which it forms an angular unconformity. It clearly indicates a period of intense deposition, both in the previously established Dhok Pathan

synclines as well as on intervening levelled ridges. from which the Upper Siwalik beds may have been eroded. Accordingly their contact in the basin is disconformable with older Upper Siwaliks, and unconformable in the adjoining highlands where the first stage may never have been recorded by sediments. This situation may well account for the assumption of previous surveyors that the Boulder Conglomerate rests conformably on earlier Upper Siwalik rocks.

Most remarkable in this section is the folding of the Boulder Conglomerate with earlier Siwalik beds. This reveals continuity of folding on a structural pattern previously achieved by Himalayan orogeny.

The Potwar silt is here underlain by tilted cross-bedded brown silt and sand which are younger than the uppermost conglomerate layer. These beds may still belong to the Boulder Conglomerate stage. The latter forms a wide greatly tilted terrace level and towards the Khad river there occur at least three other but lower terraces which are clearly not dip-slopes but erosional terraces. In these the tilting is less pronounced but slight warping, which is directed away from the anticline, can still be noticed.

5. Jammu

On the border of the foothills and near the outlet of the Tawi river at Jammu occurs a very complete sequence of Siwalik formations. Here the first author took a section along the road which follows the right bank of the Tawi river, making excellent exposures between Jammu city and Nagrota. The conspicuous ridge on which Jammu is built rises some 700 feet above the level of the plains and consists entirely of loose bouldery gravel in a reddish matrix of sand and silt. This coarse conglomerate is underlain first by an alternating series of pink and yellow clay with conglomerate layers. One receives the impression as if the coarse conglomerate grades into the lower group which dips gently (5–10°) towards the plains. Professor G. Bose, of the Prince of Wales College Jammu, drew my attention to the frequency of facetted

boulders occurring in the upper conglomerate. These boulders are either of quartzite, or less frequently of igneous rock. They display all the signs of having been smoothened and polished by ice. Here also a large waterworn flake of quartzite was found such as occur commonly in the Boulder Conglomerate near Mirpur and Rawalpindi. This upper group clearly belongs to the Boulder Conglomerate. Its thickness is about 1800 feet.

Below lies a series of alternating pink, yellow and grey silt, with sandstone layers and brown clay following upstream. These beds are more tilted than the upper group and resemble the Upper Siwaliks of the Soan and Campbellpore sections. Their Pleistocene age could be ascertained at Khanpur (arrow in Fig. 7) where coarse pebbly sandstones of grey colour yielded a molar of horse (*Equus*), isolated teeth of *Bos* and a molar of *Elephas planifrons*. This bone-bearing horizon is underlain by harder conglomerates, and brown to pink clay with freshwater shells. The total thickness of this group is approximately 2200 feet. At Nagrota[1] a slight disconformity separates the basal beds from underlying variegated clays and sandstones of typical Dhok Pathan facies. From this disconformity onward the dip of the underlying beds increases rapidly to 40 or 55° and more.

The section gives the impression as if the Upper Siwaliks form a huge fan in which two coarse horizons, namely the Boulder Conglomerate and the basal beds at Nagrota mark two stages of rapid accumulation which contrast with the more quiet sedimentation indicated by the intervening silt and clay layers. This twofold change from quiet to rapid deposition indicates two stratigraphic breaks or disconformities in an otherwise uniform sequence. The younger disconformity can be traced to an uplift of the adjoining Pir Panjal range, as Fig. 8 illustrates, while the older break is discernible in all Pleistocene sections indicative of strong uplift and folding along the mountain front at the close of the Tertiary.

[1] From this locality the Geological Museum at Jammu has *Stegodon ganesha* and *Hexaprotodon*.

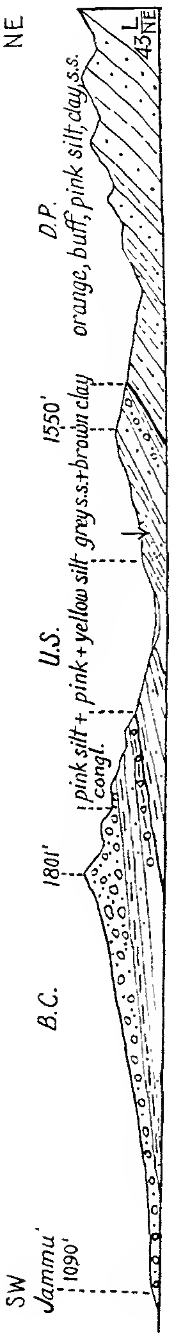

Fig. 7. Profile through front hills near Jammu

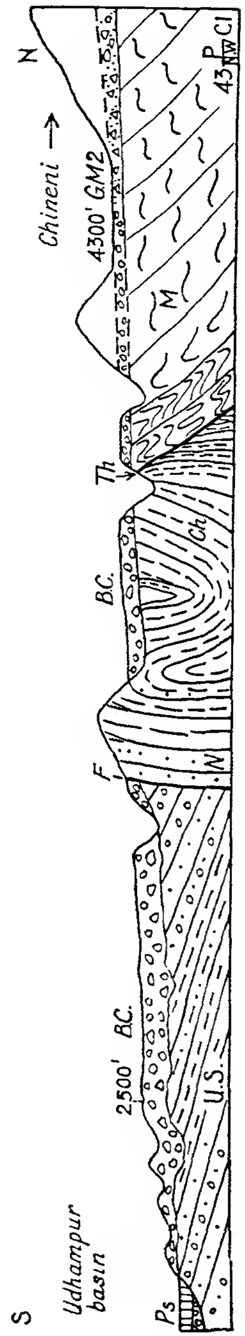

Fig. 8. Combined section along Tawi river near Udhampur

N = Nagri sandstone (middle Siwaliks); Ch = Chinji beds (lower Siwaliks); M = Murree sandstone (Miocene); F = fault; Th = thrust-fault; GM2 = ground-moraine of 2nd glaciation.

6. Tawi Valley near Udhampur

In the Himalayan foothills near Udhampur, some 15 miles north of section Fig. 7, Upper Siwalik beds occur in an isolated basin in greatly disturbed position. They constitute a thick series of grey conglomerates, sandstone and silt which are faulted against steeply folded Lower and Middle Siwaliks. Figure 8 shows this series to be unconformably overlain by a few hundred feet of conglomerates in a reddish sand matrix which build high level spurs along the northern slope of the basin. This deposit consists mainly of subangular Murree sandstone boulders and its thickness decreases notably north of a major thrust-plane (Th in Fig. 8). From here on also its composition becomes more varied until finally towards Chineni, the boulders lie in a clay matrix displaying signs of ice transport. Further upstream this deposit merges into a regular groundmoraine-filling of the Tawi valley. For reasons which will be discussed in another publication, this moraine should be considered as belonging to the second ice advance in the Pir Panjal range.

This section permits recognition of the following stages:

1. Fluvial accumulation of older Upper Siwaliks and tilting.

2. Denudation and deposition of Boulder Conglomerate, accumulation of which was determined by (*a*) erosion, released through thrust-faulting and (*b*) outwash from glacial deposits.

3. Erosion and deposition of Potwar silt (reddish) in the centre of the basin.

In this region the exact nature of the contact between the Upper and Middle Siwaliks remains to be ascertained but a steeper dip was generally noticed in the Dhok Pathan rocks which might indicate that the boundary is in the nature of an unconformity. The section demonstrates the dependence of the boundary between the two Upper Siwalik stages on the structural pattern, and it also shows that the unconformity is inevitably connected with a new drainage plan, initiated by a second orogenic phase.

III. Salt Range Area

This unit comprises the elevated, hilly as well as mountainous, tract between the Jhelum river in the southwest and the Potwar area in the northwest. The four sections described below lie on the slopes of the Salt Range anticlinorium, the central portion of which is sketched in Fig. 12.

7. Jhelum

Northwest and southeast of Jhelum city two anticlinal ridges mark the southern limit of the Siwalik folds. Their composition and structure, as interpreted in Fig. 9, is exceptionally suggestive.

In the northwestern ridge at Rohtas, the Boulder Conglomerate is represented by a conspicuous agradational terrace, making a 200 foot layer of quartzitic boulders loosely embedded in a red silty sand (Mirpur facies). On the crest of the ridge the conglomerate is dissected whereas on the slope it displays a wide level, clearly tilted towards the Jhelum valley. Younger gravels of different composition rest against the slope of the ridge.

The conglomerate overlies unconformably an anticline, the core of which is composed of Dhok Pathan rocks, such as grey-white sandstones, orange and red clays. This core is overlain, without any angular break, by a series of grey and mauve, soft and micaceous sands with alternating brown clays and conglomerate layers. At the southern entrance to the Rohtas gorge these beds stand vertically, and the ridge here breaks abruptly down to the valley floor. No fossils were found in this series but their lithological character sufficiently proves the Upper Siwalik age.

In the southeastern ridge, the so called Pabbi Hills, Dhok Pathan rocks do not emerge. Instead a thick, rhythmically deposited sequence of mauve, yellow and grey sands and silts appears which is surely referable to the older Upper Siwaliks. This is proved by the fossil fauna which we collected at Locality 104, at the crest of the ridge. Dr. Colbert determined from our collection the following forms: *Stegodon*

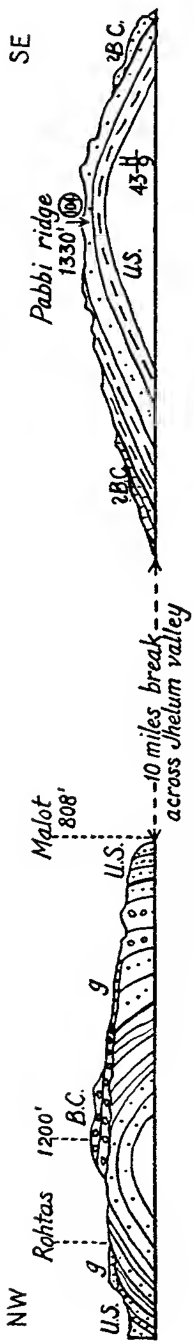

FIG. 9. Combined section through Siwalik folds near Jhelum

g = terrace gravel.

insignis, *Archidiskodon planifrons* (equals *Elephas planifrons*), *Cœlodonta platyrhinus*, *Rhinoceros sivalensis*, *Sus falconeri*, *Hexaprotodon sivalensis*, *Cervus sivalensis*, *Sivatherium giganteum*, *Taurotragus latidens*, *Bos acutifrons*, *Antilopine* horn-core.

Along the flanks of the ridge but especially on the north-western slope, there appears a thick group of yellow and pink silts and yellow loam with small size conglomerate layers at the base. These beds resemble the Potwar silt to a certain degree but the greater variety of composition, the presence of thick basal gravels and the tilting rather argue for the presence of the Boulder Conglomerate stage.

If the observation is right that in the Rohtas section the Boulder Conglomerate is warped, and if it is true that in the Pabbi Hills the flanking beds are of late Upper Siwalik age, we may conclude that the folding of the former is anterior as a whole to the structure of the Pabbi Ridge in which the contact with the older Upper Siwaliks is conformable. This situation would suggest "propagation" of a crustal fold from the Salt Range anticlinorium towards the Punjab plains. If, on the other hand, the Boulder Conglomerate is absent in the Pabbi Hills, and not warped in the Rohtas section, then we would simply have another example of a clear unconformity between the Boulder Conglomerate and the older Upper Siwaliks.

8. Tatrot

Some 20 miles westsouthwest of the Rohtas section, the Salt Range forms two ridges one of which makes an anticline with NE strike whereas the other is in continuation of the northern anticline described in Fig. 9. Between them lies a basin which is occupied by folded Siwalik formations. The village of Tatrot lies almost on the boundary between Dhok Pathan and younger rocks which in the past have yielded many fossils. Evidently Pilgrim chose the name Tatrot for his lowest stage of the Upper Siwalik group on account of this fossil wealth which is now almost exhausted. Stratigraphi-

cally Tatrot is one of the least complete sections which we studied and would for this reason in our opinion not deserve to be mentioned in this discussion were it not for the reputation which the name Tatrot has gained in Indian geological literature.

Section Fig. 10 was taken in the middle portion of an escarpment which at Tatrot is built of resistant layers of grey conglomeratic sandstone. Below we found two similar, yet coarser and thinner beds, the lowest of which is composed of rounded and subangular pebbles of pink granite, porphyrite, various quartzites, chert and purple sandstone. A similar, yet even coarser composition is found in the upper conglomerate. Lithologically these beds contrast with the underlying

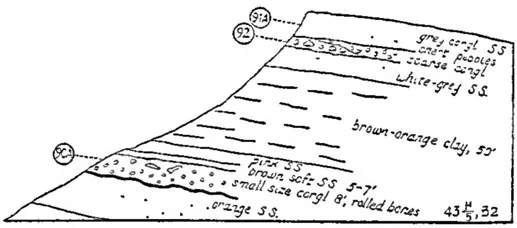

FIG. 10. Basal Pleistocene near Tatrot

Dhok Pathan rocks in which orange and pink colours prevail and in which the pebble components are different and less varied. The basal conglomerate therefore signifies a break in sedimentation due no doubt to a different supply of sediment which can be traced to the Paleozoic rocks emerging in the neighbouring Salt Range. At that time these older formations evidently were for the first time denuded, and it is reasonable to conclude that such process was brought about by uplift of the southern Salt Range tract. The younger beds then settled in a syncline, previously established, and recorded the new conditions in their lithology.

At the same time a new fauna appeared in this region. In the lower conglomerate (Fig. 10, 90*A*) we found only rolled bones, single teeth of *Bovids* and of *Hipparion* which fragments might, under the existing conditions, easily have been

derived from underlying Dhok Pathan rocks. In the next layer a horn-core of *Gazella* was found and in the upper sandy conglomerate (Fig. 10, 92) an unworn jaw of *Sus hysudricus*. From information received by Dr. Colbert it seems that Mr. B. Brown collected in the upper layer (at the Am. Mus. locality 139, near 91*A* of Fig. 10) *Stegodon* sp., *Antelope* cf. *subtorta* (det. Pilgrim) and a molar of *Hipparion antilopinum*, and *Hippohyus lydekkeri*. In 1935 Mr. Aiyengar collected a few miles west of Tatrot from similar beds a skull of *Hemibos occipitalis* and *Hexaprotodon sivalensis*. The only discordant type in this otherwise Pleistocene fauna is *Hipparion* of which only single molars or fragments of such were collected. The evidence, cited above, for re-deposition of a few resistant fossil fragments of Dhok Pathan age, is highly suggestive of a possible mixture in these basal beds at Tatrot of a few Dhok Pathan forms, such as *Hipparion*, with Pleistocene types. It is this consideration which makes us think that the basal portion of the Upper Siwaliks at Tatrot is equally as old as the lower group at Jammu or Campbellpore.

At Hasnot and further westward the Siwaliks are overlain by coarse limestone conglomerates which cap the levelled edges of the earlier formations. It seems that they represent in parts the Boulder Conglomerate.

9. Bhaun

About 32 miles west of Tatrot lies another basin, adjoining the northern flank of the Salt Range. Here section Fig. 11 was studied along the Sauj Kas, a valley south of Bhaun, representing in parts the continuation of a profile previously described by de Cotter and Lahiri.[1] The authors gave a good interpretation of the angular conformity between Dhok Pathan and Upper Siwalik stages. As at Tatrot the latter begin with a basal conglomerate which the above named interpreted rightly as the beginning of a new cycle of sedimentation, initiated by uplift of the adjoining Salt Range.

[1] *Memoirs, Geol. Survey of India*, 62, 1933.

In the upper portion of the grey and brown coloured gravels and sands (few red clays intercalated) appears another conspicuous conglomerate (*C*2 in Fig. 11) which seems to dissect the underlying cross-bedded micaceous sands. Here we collected a toothless mandible of *Hippopotamus*, bones of *Proboscideans*, turtle shells, teeth of crocodile and a phalanx

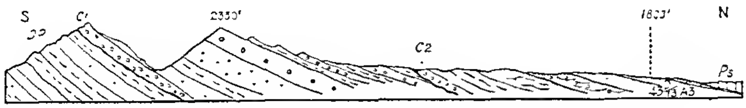

FIG. 11. Pleistocene sequence along Sauj Kas near Bhaun

*C*1 = basal conglomerate; *C*2 = basal layer of Boulder Conglomerate; total length ca. 2 miles.

of *?Camel.* The overlying series of pink silt and gravelly sand repeat the composition of the Boulder Conglomerate, as observed in the Soan valley, and should therefore be of similar age.

The Potwar silt covers a relief cut into the Upper Siwalik formation, and its thickness increases rapidly as one approaches the centre of the basin near Bhaun.

10. Naoshera

The foregoing sections already suggest that the Salt Range had undergone severe denudation in Upper Siwalik time, and they also indicate that the Upper Siwaliks had originally covered a wider area of its elevated tract. Conclusive proof for this was found in the Central Salt Range at Naoshera where a basin, about 5 miles wide, is underlain by Upper Siwalik and younger beds which are faulted along the slopes of the flanking Eocene limestone ridges.

Figure 12 gives a cross-section through the southern part of the basin, south of Naoshera. Here the basal group, consisting of thick grey or pink conglomerates, sandstones and clays, is overlain by more brightly coloured beds of finer texture. The conglomerate beds yielded a few rolled bones of artyodactyl mammals, also teeth and jaw fragments of *Bos*, displaying the poor fossilisation typical for many Upper

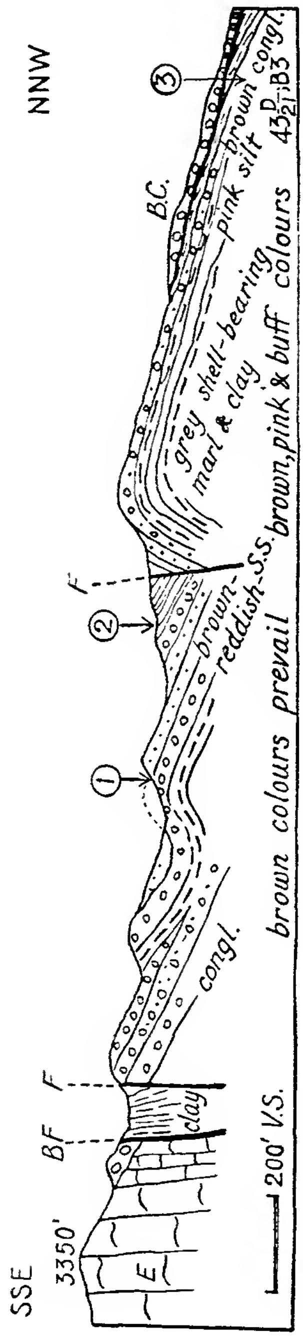

FIG. 12. Folded and faulted Pleistocene near Naoshera

Total length ca. 2 miles.

Siwalik fossils. This series is essentially a unit as compared with a higher group of bouldery limestone conglomerates and sands which overlie the dissected edge of the tilted group. The conglomerate is made exclusively of subangular Eocene limestone boulders, indicative of rapid erosion in the nearby Eocene limestone belt. The older conglomerates of the lower group reflect on the other hand by their great variety of pebbles (purple sandstone, shells of *Productus*, silicified wood, quartzites, etc.) a widespread denudation of the entire Salt Range with its complex association of Paleozoic to Cenozoic rocks. Here again as at Bhaun, Jammu and other places, two distinct cycles of sedimentation appear, one comprising the older Upper Siwaliks, the other the Boulder Conglomerate stage. The composition of the latter clearly reflects differentiation of the relief into single units from which selected rock waste was deposited in the lowlands. The section shows also severe crustal deformation, both normal faulting as well as folding, which are in themselves proof for the mountain uplift at the close of older Upper Siwalik time.

C. Observations on Post-Siwalik Formations

Although the scope of this report is essentially to demonstrate the character of the Upper Siwalik beds it seems, nevertheless, essential to refer briefly to some post-Siwalik stages. This will help to clarify the meaning of the term "Upper Siwalik" because it will show that their two stages, if taken together, belong clearly to that large, impressive pile of Himalayan foothill sediments which is called "Siwaliks."

1. The Lœss-like Potwar Silt and Its Possible Origin

Most of the sections discussed above contain a series of deposits which has been called "Potwar silt." This may be divided into two horizons, a thin basal gravel or sand, and an overlying mass of commonly yellow, sometimes also pink silt which at places reaches a thickness of 350 feet.

The lower horizon generally shows signs of fluvial deposition, dependent in its gravel composition on the underlying

relief. The overlying silt is of remarkable uniformity, so much so that one is tempted to call it lœss, as Wadia [1] and others have done. In favour of this definition are the following characteristics: relative uniformity of composition, widespread occurrence independent of any physiographic obstacles, and local relationship with glacial deposits along the mountain front. The latter phenomena became clear only through recent glacial studies which Paterson and de Terra carried out in Kashmir and Poonch.

This cannot be fully discussed in this paper, and it should suffice to state here that the Potwar silt in the Soan area is cut into by a terrace, which is the third in a uniformly observed system of five terraces. In regions closely adjoining the Potwar plain, namely in Poonch, in Jammu and Kashmir, we found terrace 3 cut into the moraines of the third glaciation. This we took to indicate that it originated during the retreat phase of the ice and in the following third Interglacial, while terraces 4 and 5 (of depositional nature) would represent the fill stages of the fourth and fifth ice advances. Based on such observations, which will ultimately be fully discussed in a larger memoir, is our suggestion that the Potwar silt originated during the third glaciation when valley glaciers extended in Poonch down to a level of 4500 feet, or some 2500 feet above the higher regions at which the silt was encountered.

This relationship with the glacial cycle would speak in favour of the windblown origin of the Potwar silt, but other features seem to argue against this supposition. These are: uniform stratification in layers from a fraction of an inch to one foot thick, local occurrence of freshwater shells, and dependence of maximal thicknesses upon drainage lines, which here very often correspond with synclines. Such properties appear at first incompatible with the idea of windborn drift unless one could conceive an atmospheric agency which caused rhythmic precipitation of silt. In such a case stratification would naturally follow, provided that the surface soil was given a chance to accumulate.

[1] *Mem., Geol. Survey of India*, 51, Pt. 2. 1926.

In this connection the first author calls attention to rhythmic precipitation of silt which occurs annually in Northwest India during the monsoon period. Here the semi-arid nature of the plains and the presence of silt stored up in thousands of feet of Siwalik rocks, provide for conditions favourable to dust-storms of great dimensions. These occur commonly in the spring and seem to reach their greatest force along certain "wind-tracts," as in the Soan and Indus valleys, where enormous quantities of loose silt are then whirled up. At this time the air is so charged with dust that it hangs like a thick veil over the landscape blotting out all details and even contours of mountain ranges. This phenomenon prevails for months (in April, May and half of June) during which time only few local thunderstorms temporarily clear the atmosphere. But once the monsoon rains "break" this dust veil is quickly torn down, and rain drops precipitate it as a film over the landscape. Here it accumulates more rapidly in depressions than on high ridges, and besides rainwash and increased stream action re-distribute it along drainage channels. Silt deposits resulting from this process are laminated, but if one pictures a larger silt supply and greater precipitation it is evident that the laminæ must grow into regular layers. Such conditions could easily have prevailed during the Pleistocene, at a time when the Himalayan glaciers began to expose thick groundmoraines in the mountainous tract and rivers intensified their erosion in the silt bearing Siwalik beds. Some sort of monsoon must have existed in this region, as it does nowadays, and its influence must have been felt in dust-storms of much greater proportions. In this case silt of uniform appearance would have precipitated in greater quantities along drainage channels, and land as well as freshwater molluscs might have existed anywhere. In fact this "pluvial lœss," as one might call it, would combine the properties of wind and river drift although the former would always dominate its lithological character. In many respects such a deposit can be mistaken for a lake bed. That the Potwar is not a lake deposit becomes evident

from its distribution which is independent of any natural barrage. Also it can not be entirely of fluvial origin, for it is found on top of watersheds as well as in valleys, lying in the central Salt Range at 2600 feet and in the Jhelum valley 900 feet above sea-level.

Physiographically the Potwar silt makes for "badlands" and creates often a regular loess landscape. It always fills an older relief which developed subsequent to the deposition of the Boulder Conglomerate. The intervening period then was one of long lasting erosion during which the present drainage pattern had principally developed: wherever the Potwar silt covers an anticline in the upward movement of which the Boulder Conglomerate has visibly taken part, one can observe slight tilting. It is of course difficult to decide whether in such cases the silt layers adjusted themselves to dip slopes during their deposition or whether they were subsequently disturbed by further upward bulging of the anticline. The tendency of the silt to accumulate thicker in synclines than on intervening ridges was often observed, even at such places where no larger drainage channels occur. This feature would point to slight deformation in post-Potwar time at which phase terraces 2 and 3 encountered tilting all along the Pir Panjal. The possibility of such a late movement in the adjoining plains can therefore not be ignored.

2. *Re-deposited Potwar and Younger Gravels*

Along the tributaries of the Soan river near Rawalpindi, as also in the central Salt Range and near Jhelum, valleys and smaller stream channels are filled up with a yellow or pinkish loam. This deposit reaches at places great thickness and its gravel layers and cross-bedding generally point to fluvial origin. Very often terrace 4 is made of this material which suggests a definite relationship with the fourth glacial advance in the mountains.

Along the Soan valley were found very small cores and flakes of agate in this deposit which indicate a prehistoric culture of possibly late Paleolithic age. The thickness of the loam varies greatly with the size of the stream channel in

which it was deposited and it generally increases where the Potwar silt is thickest. This relationship suggests denudation of the Potwar silt and subsequent re-deposition by river action; at some places however, as for instance on high hillocks of Potwar silt, this loam is unstratified and independent from valleys. This position therefore recalls the distribution of Potwar silt which suggests that the loam represents, in parts at least, a later lœss, connected perhaps with the fourth glaciation in the mountains.

D. Conclusions as to Age and Character of the Various Stages and Their Relationship to Early Human Cultures

Our observations on Upper Siwalik and later formations in the Northwest Punjab permit in our opinion of the following conclusions:

(1) The nature of the boundary between Dhok Pathan and Upper Siwalik stages (Pliocene-Pleistocene boundary) is determined by the structural pattern in the Himalayan foothills. Consequently it is disconformable in synclines which received the new rock waste from an uplifted area in the neighbourhood, and unconformable at such places where previously established basins were disturbed in late Dhok Pathan time, or where new basins came into existence (Campbellpore, Naoshera). In all cases a sedimentary break exists (disconformity) which can be traced to uplift of adjoining regions. This break is indicated by

(*a*) basal conglomerates, proving a total change of sedimentary supplies;

(*b*) different colouring of Upper Siwalik beds in which sombre colours of brown, grey and pink prevail;

(*c*) poor consolidation in contrast to the underlying hard Dhok Pathan rocks:

(*d*) independence of distribution of Upper Siwaliks in individual basins, such as at Naoshera and Campbellpore.

(2) Similarly, the contact between the two Upper Siwalik stages is dependent on structure, for an angular unconformity

exists where the older beds had suffered folding or faulting as at Campbellpore, Udhampur and Rohtas. In other regions, deposition took place during subsidence previously begun in synclines (Soan, southeast of valley) in which case the contact is in the nature of a disconformity. The Boulder Conglomerate reflects in all cases a sedimentary break due to new orientation and rejuvenation of the drainage in which is reflected a second important phase of mountain making.

(3) At least three diastrophic phases become evident: one of latest Dhok Pathan time, a second of pre-Boulder Conglomerate and a third of pre-Potwar time. Most likely a fourth but less vigorous movement set in after the Potwar silt was laid down. The three important phases are common to both the Himalayan and the Salt Range tracts, thus revealing an interrelationship between Himalayan orogeny and Salt Range tectonics. In conformity with previous studies on Himalayan structures [1] it can be said that the successive sedimentary release of coarse detritus at the beginning of each stratigraphic stage as also the successive addition of new folds (Fig. 9) indicates progression of a lawful diastrophism connected with Himalayan mountain making, with an outspoken tendency of crustal movement towards the south. Such a process would explain the extraordinary coördination of young tectonic movements between the Salt Range (outlayer of the rigid Indian land mass) and the Himalaya (mobile belt), which mountain region evidently not only grew in height but widened its folded belt towards Peninsular India.

(4) If only the fossils are taken into consideration, it seems that most of the anomalies found in the faunal lists of previous investigators would disappear. All the specimens collected by ourselves make a distinct coherent fauna (*Stegodon*, *Elephas*, *Equus*, *Bos*, deer, *Sivatherium*, etc.) in which no discordant types such as *Mastodon* and *Merycopotamus* appear, and apparently no *Hipparion* either if one accepts the ex-

[1] H. de Terra, "Himalayan and Alpine orogenies." Rep of the 16th Intern Geol. Congress, Washington, 1934.

planation for the presence of a few stray molars at Tatrot which was given on p. 809.

(5) According to our observations a division of the Upper Siwaliks in Tatrot and Pinjaur stages is largely arbitrary and nominal. Subdivisions, based on certain differences in the fauna, may eventually be recognised, but on the whole the older Upper Siwalik stage represents one single cycle of sedimentation, such as is well documented at Campbellpore.

(6) The age of the Upper Siwaliks is old Pleistocene or early to Middle Pleistocene if a threefold division of the Pleistocene is employed. This conclusion is based on the simultaneous appearance of *Elephas*, *Stegodon*, *Equus* and *Bos* in the basal group and on the correlation of the Boulder Conglomerate with glacial deposits. The more recent faunistic studies of Matthew [1] and Colbert [2] led to similar conclusions.

Impressive as this crustal evolution is, it seems of lesser importance in comparison with the first appearance of Man at the very close of Siwalik time. From various places along the Soan valley, as also in the foothills of Jammu and Poonch the authors and Mr. Paterson collected a variety of stone tools and flakes which were found in upper gravels of the Boulder Conglomerate. These represent an early Paleolithic culture in which Chellean and Acheulean handaxes, choppers and flakes dominate. One site, in the Soan valley south of Chauntra proved to be especially rich in slightly worn Chellean tools which were found in a gravel apparently belonging to the basal Potwar series. These tools, some of which recall the Madras Chellean of Southern India, were evidently redeposited from an earlier gravel of pre-Potwar age which is here preserved in patches overlying Dhok Pathan rocks. Otherwise it would be difficult to explain the fresh preservation of another Stone Age culture which was found with the Chellean tools. This industry more commonly is met with in the basal gravel of the Potwar or on the surface of terrace ledges

[1] W. D. Matthew, "Critical Observations upon Siwalik Mammals." *Bull. Am. Mus. Nat. Hist.*, **56**, Art. VII, pp. 437–560.

[2] E. H. Colbert, "Siwalik Mammals in the Am. Mus. Nat. Hist.," *Trans. Am. Phil. Soc.*, New Ser., **26**, 1935.

from which the overlying silt had been removed by erosion. The implements, most of which are made of quartzite, are generally cruder than the early Paleolithic tools, choppers, scrapers, blades and worked flakes being prominent at many places. Heaps of flakes and cores indicate locally the relics of "workshops" of these ancient people whose technique of rock flaking developed on its own lines possibly from early Paleolithic to late Middle Paleolithic times. At this moment when a closer examination of the typological evolution of the "Soan culture" is still under way, it is difficult to say what stages of the Middle Paleolithic are represented. According to Paterson the Soan industry is essentially Clactonian with Levallois influence. The fact that we collected thin quartzite flakes with prepared striking platforms in the basal portion of the silt, indicates that Early Man lived in this region for long periods of time, and that he slowly progressed in his primitive stone industries.

E. Supplementary Note on the Pleistocene of the Narbadda Valley in Central India

In the Narbadda valley of the Central Provinces, between Hoshangabad and Narshingpur, Pleistocene beds form an old river terrace, some 120 feet above the stream. These deposits have long been known to contain Pleistocene fossils and also artifacts of which few had been collected by Seton Karr and others.

As indicated by Fig. 13 the formation consists here of two different horizons, each of which begins with a basal gravel overlain by brown and pinkish or orange coloured concretionary clays and silts. In the lower zone the conglomerate is coarser and more cemented, the clay is more intensely coloured and also richer in concretions than in the upper zone.

Fossils occur chiefly near the disconformity which separates both zones. We extracted from the base of layer 4, Fig. 13, skull fragments of *Bos namadicus*, *Bubalus*, *Elephas namadicus* (several jaws) and *Hexaprotodon*. Near Umaria was found in layer 4 a skull of *Bos namadicus*. In the lower zone we collected near Hoshangabad *Equus namadicus*,

Hexaprotodon, *Elephas namadicus* and isolated teeth of *Bos*.[1] A closer study of our specimens might possibly detect a difference in fauna between the lower and upper zones.

In close association with these fossils we found abundantly prehistoric implements which seemed to be especially frequent in the gravel layers. In the lower zone appeared dominantly Chellean and Acheulean hand-axes, cleavers and flakes. Some of the Acheulean tools were absolutely fresh in appearance. In the upper zone we collected mainly chipped boulders, cores and flakes of quartzite and trap which recall the typological aspect of the Soan industry in Northwest India.

Outside of the valley the Pleistocene sequence is supplemented by an old laterite bed which emerges locally, as at

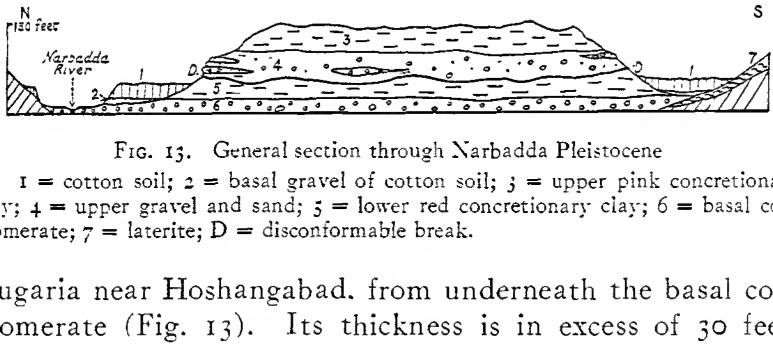

FIG. 13. General section through Narbadda Pleistocene

1 = cotton soil; 2 = basal gravel of cotton soil; 3 = upper pink concretionary clay; 4 = upper gravel and sand; 5 = lower red concretionary clay; 6 = basal conglomerate; 7 = laterite; D = disconformable break.

Tugaria near Hoshangabad, from underneath the basal conglomerate (Fig. 13). Its thickness is in excess of 30 feet. Obviously then the laterite originated prior to the basal zone of the Narbadda sequence which itself is devoid of any traces of lateritisation. The fact that laterite was preserved on the slopes of the Narbadda basin, and not in the valley might indicate a period of intense erosion which preceded the deposition of the lower gravels. The contact between both formations should be regarded as a major break, comparable with the disconformity between the older Upper Siwaliks and the Boulder Conglomerate stage in Northwest India. This relationship makes it highly probable that the laterite represents the early Pleistocene.

The "lower zone" of the Narbadda Pleistocene can be equated with the Upper Siwalik "Boulder Conglomerate" on

[1] All fossils are Pleistocene. No molar of *Stegodon* has ever been found, and as for *Leptobos* no certain trace of it has so far been discovered.

faunistic, archeological and lithological grounds. The association of advanced *Elephas* with *Hippopotamus* and large *Bos* suggests a stage slightly younger than the older Upper Siwaliks. In harmony with this is the appearance of an early Paleolithic culture in the basal gravel, clearly calling to one's mind the picture of heavy accumulation of river deposits during the glacio-pluvial stage of late Siwalik times in the Punjab. It follows that on these grounds a further correlation between the "Upper Zone" and the "Potwar silt" becomes rather plausible. Both are separated by a long erosion inter-

Age		NW-Punjab	Kashmir Valley	Narbadda Valley
Pleistocene	Upper	re-deposited Potwar and second lœss	4th Glacial	Cotton soil
		Erosion interval	3rd Interglacial	Erosion interval
		Potwar silt	3rd Glacial	Upper zone
	Middle	Long erosion interval	2nd Interglacial	Erosion interval
	Middle (Upper Siwaliks)	Boulder Conglomerate	Upper Karewa beds 2nd Glacial Karewa gravels	Lower zone
	Lower (Upper Siwaliks)	Pinjaur zone	1st Interglacial	?
		Tatrot-zone	1st Glacial	Narbadda laterite
Pliocene		Dhok Pathan-zone	Missing	Missing

FIG. 14. Correlation table of Pleistocene sequences
Undulating line = major breaks, generally marking crustal disturbances.

val from the underlying beds and both contain implements of Soan type. The cotton soil might then well represent the latest Pleistocene which possibly is homotaxial with the re-deposited Potwar silt and the second lœss in the Punjab.

In Fig. 14 we have made an attempt to correlate the Pleistocene sequences in the three main fields of investigation.

We believe that this correlation opens up new perspectives for the Pleistocene geology of India and its human prehistory. Beyond India it will eventually have a definitive bearing on pending questions pertaining to the evolution of Man in southern Asia and to climatic changes in non-glaciated regions.

THE COMMUNICATION OF THE PNEUMATIC SYSTEMS OF TREES WITH THE ATMOSPHERE

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(*Read April 23, 1936*)

ABSTRACT

The woody cylinder of trees is partially occupied by the sap forming the hydrostatic system and by atmospheric gases constituting the pneumatic system, which has a volume at barometric pressures equivalent to 20 to 40 per cent of that of the trunk. The proportions of the gases in the tree are widely different from those of the air and may vary widely throughout the season or from day to day, being commonly characterized by high proportions of carbon dioxide; in exceptional cases high proportions of oxygen have been found. The pneumatic system usually stands at pressures differing no more than 5 to 15 mm. from that of the air surrounding the trunks, which implies some communication.

Gases move longitudinally in the wood cells in tree trunks with great freedom, but a cylindrical shell of 10 to 20 layers of living cells forms a complete sheath around the woody cylinder. No passages through this cambial layer can be demonstrated microscopically, nor is it pervious to water solutions. It has been found, however, that differences in pressure of 5 to 30 mm. of mercury will cause air to stream into or out of tree trunks across the living layer of cambium and young derivatives by which the presence of minute passages is demonstrated.

An apparatus has been designed to measure the rate of flow under various pressures. Suction of 95 to 100 mm. of mercury on the ends of small stems with 5 to 9 layers of wood caused an inflow of air into stems of the Monterey pine 0.004 to 0.044 coast redwood 0.010 to 0.019, willow 0.002 to 0.009, California live oak 0.016 to 0.090 and an Arizona desert oak 0.012 to 0.060 cc. hourly per sq. cm.

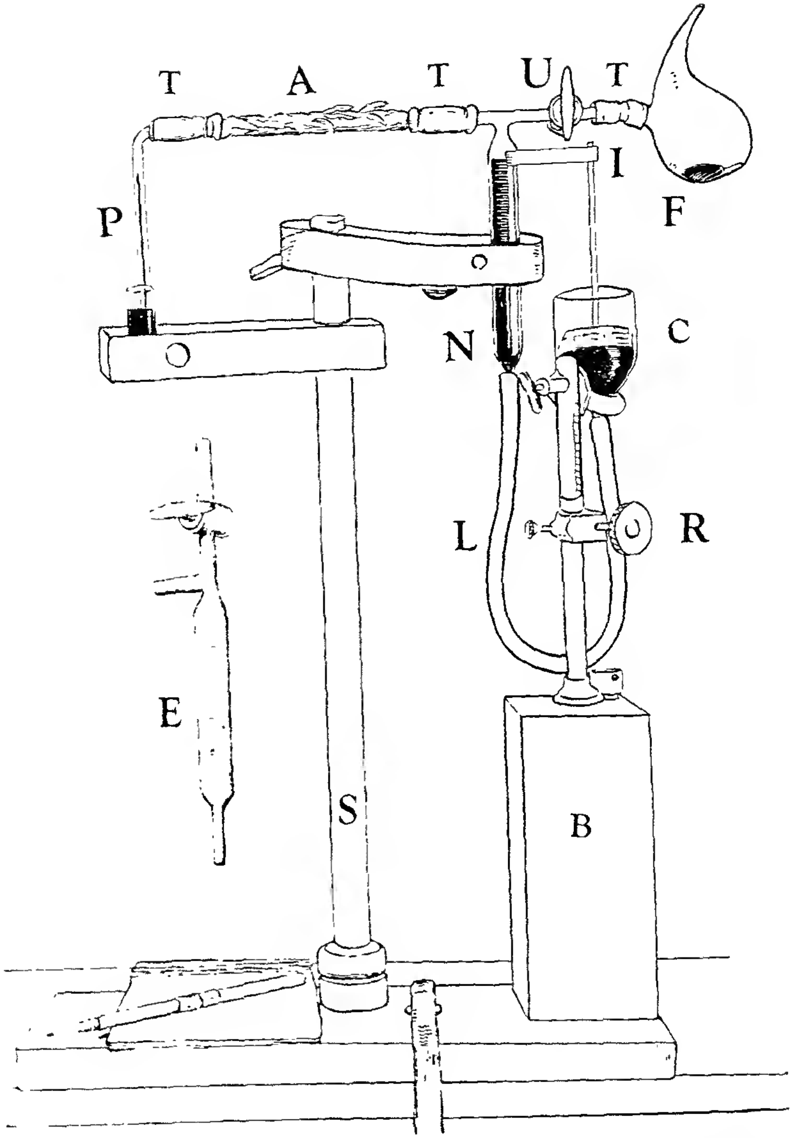
These results make it clear that variations in barometric pressure would result in some streaming movements of gases, into or out of tree trunks. Carbon dioxide is continuously released by respiratory and possibly other processes in the trunk; some of it is dissolved in sap and is carried to the leaves. Any resultant increase in volume would set up pressures and cause outward streaming at rates indicated by the measurements given.

THE composition and other features of the pneumatic system of trees was the subject of a brief paper presented to the Society in 1932,[1] while a more comprehensive treatment appeared elsewhere in the following year.[2]

Air occupies the spaces in the trunk not filled with sap. The included gases, which are those of the atmosphere, may

[1] MacDougal, D. T. "The Pneumatic System of Trees." *Proc. Amer. Phil. Soc.*, **71**, No. 5, 1932.

[2] MacDougal, D. T. and E. B. Working. "The Pneumatic System of Plants, especially Trees." Publ. 441, Carnegie Inst. of Wash., 1933.



[illegible] measuring rate of penetration of [illegible] *T.T.T.* Connections of rubber [illegible] *P.* [illegible] suction through length of [illegible] rubber tubing *L*, with graduated [illegible] relief cock in vertical arm. *F.* Bulb [illegible] of extraction system. This bulb is at- [illegible] *R.* [illegible] screw of rack and pinion [illegible] *B.* Base of extraction [illegible] stem and burette.

move freely up or down the trunk but communication radially with the atmosphere is restricted, for the pneumatic system is completely enclosed by the cambium and its derivatives; this is a layer 12 to 20 living cells in thickness.

The existence of channels through which gases might flow across the living layer has been variously asserted and denied by anatomists. In any case these would be so small, tortuous and indefinite as not to be satisfactorily demonstrable by the microscopist. The results of tests given below establish beyond doubt that passages through which atmospheric gases may pass by streaming are present. The cortical layer outside of the cambium has relatively large intercellular spaces which communicate freely with the outside air.[1] This part of the tree is well ventilated, and the air in contact with the outer side of the living cylinder furnishes a normal atmospheric supply of oxygen. The air inside the living layer, or the pneumatic system rarely includes an equivalent proportion of oxygen, and samples have been taken from trees showing none of this gas, while carbon dioxide may be present to the extent of 100 to 3,000 parts in 10,000, this gas being present as only 3 or 4 parts in ten thousand in the air. While these disproportions imply a high diffusion gradient, yet equalization by solution and diffusion proceed but relatively slowly.

In order to test the rate of flow of gases into and out of stems and trunks experiments were carried out as follows, principally with sections of stems 10 to 20 mm. in diameter and 10 to 20 cm. in length. Such sections (Fig. *A*) chosen for their soundness and freedom from injury were freshly taken from trees, the bark, cortex and cambium removed from about 10 to 12 mm. at both ends over which were sealed short pieces of rubber pressure tubing (Fig. *T*) about 3 cm. long, using a thick liquid shellac. This preparation was now connected with the horizontal arm of specially designed burettes of

[1] MacDougal, D. T. "Air-passages in the Cambium Layer of Trees." Yearbook No. 31, Carnegie Inst. of Wash., Dec. 1932, p. 193.

which two types are shown in Fig. (*N*), (*E*). The free end was fitted with a section of barometer tubing (*P*), the lower end of the vertical section of which stood in a dish of mercury just below. All connections were made secure by twisted wire bands after being sealed. An open cistern (*C*) of mercury was attached to the lower end of the burette by a length of pressure tubing (*L*) 30 cm. in length. All air was now expelled from the burette and its connections with the stem. and the cistern of mercury adjusted to a level which would give a suction of 100 mm. of mercury on the end of the stem as indicated by the horizontal strip (*I*) on the upper end of the glass rod rising from a cork disk floating on the mercury.

When such an arrangement was properly made the mercury in the vertical tube (*P*) attached to the other end of the section would rise to a level within 2 or 3 mm. of that in the cistern on account of the free longitudinal communications in stems. All precautions having been observed the observer was now ready to note the amount of gas which would be extracted from the stem by the suction indicated which of course was the amount which passed into the stem through its bark and cambium layer. When as much as 2 to 4 cc. of air had thus been drawn into the burette. the amount was noted, the stopcock (*U*) was opened, the air expelled and the column of mercury once more set at 100 mm. These observations in actuality measured the rate of flow of air into stems at suctions of 95 to 100 mm. Hg.

The cistern was carried on a metal column with a rack and pinion extension (*R*) to make accurate adjustments. An upright wooden rod (*S*) with clamps of the same material supported the burette and the attachments of the section of stem. Tests of the rate of flow of air into small stems of five species of trees were made: Monterey pine (*Pinus radiata*), Coast redwood (*Sequoia sempervirens*), arroyo willow (*Salix lasiolepis*), an Arizona mountain oak (*Quercus hypoleuca*) and the California live oak (*Q. agrifolia*).

Detailed measurements are given below:

RATE OF INFILTRATION INTO PINUS RADIATA. RESTING CONDITION

No. 1

Dec. 3, 1932. 9:30 a.m. Basal section of small tree. 8 layers of wood, 13 cm. long, 12.0 mm. diam. Free surface = 38 sq. cm.
Dec. 4 9:00 a.m. 4.2 cc. 23.5 hrs. = 0.178 cc. hourly
0.005 " per sq. cm.
Reset
Dec. 6 9:00 a.m. 4.4 " 24.0 " = 0.183 " hourly
0.005 " per sq. cm.
Dec. 7 9:30 " 4.1 " 24.5 " = 0.167 " hourly
0.004 " per sq. cm.
Dec. 8 9:00 " 3.5 " 23.5 " = 0.149 " hourly
0.004 " per sq. cm.

No. 2

Dec. 5, 1932. 10:00 a.m. Section similar to No. 1. 8 layers of wood, 14 cm. long, 11.5 mm diam. Free surface = 40 sq. cm.
4:40 p.m. 7.0 cc. 6.5 hrs. = 1.077 cc. hourly
= 0.027 " per sq. cm.
Dec. 6 3:30 " 6.8 " 6.5 " = 1.047 " hourly
0.026 " per sq. cm.

No. 3

Dec. 4, 1932. 10:00 a.m. Section of stem. 7 layers of wood, section 15 cm. long. Diam. 9.5 mm. Free surface = 34 sq. cm.
Reset
Dec. 6 9:00 a.m. 4.8 cc. 24.0 hrs. = 0.200 cc. hourly
0.006 " per sq. cm.
Dec. 7 9:30 " 4.0 " 24.5 " = 0.163 " hourly
= 0.005 " per sq. cm.
Dec. 8 9:00 " 3.2 " 23.5 " = 0.136 " hourly
= 0.004 " per sq. cm.
Dec. 4 10:00 a.m. Section from slender tree. 7 layers of wood, 15 cm. long, 10.3 mm. diam. Free surface = 40 sq. cm.
Reset
Dec. 6 9:00 a.m. 5.8 cc. 24.0 hrs. = 0.241 cc. hourly
0.006 " per sq. cm.
Dec. 7 9:30 " 5.1 " 24.5 " = 0.208 " hourly
0.005 " per sq. cm.
Dec. 8 9:00 " 4.0 " 23.5 " = 0.170 " hourly
0.004 " per sq. cm.

No. 5

Dec. 5 9:30 a.m. Section of slender stem. 7 layers of wood, 15 cm. long, 10.0 mm. diam. Free surface = 38 sq. cm.
4:30 p.m. 8.2 cc. in 7.0 hrs. = 1.171 cc. hourly
0.031 " per sq. cm.
Dec. 6 9:30 a.m.–
3:30 p.m. 5.1 cc. " 6.0 " = 0.850 " hourly
0.024 " per sq. cm.

No. 6

Dec. 11, 1932.	Section of stem, same internode as No. 7. 9 layers of wood, 10 cm long, 11.5 mm. diam. Free surface = 25.0 sq. cm.			
Dec. 12	9:00 a.m.	Reset.		
	4.00 p.m.	6.0 cc.	7.0 hrs.	= 0.855 cc. hourly 0.034 " per sq. cm.
Dec. 13	2:00 "	4.2 "	5.5 "	= 0.764 " hourly 0.031 " per sq. cm.
	8:00 a.m.	5.0 "	6.0 "	= 0.833 " hourly 0.033 " per sq. cm.
Dec. 14	8:30 "	Down to 55 mm.		
	Reset			
	2:00 p.m.	5.0 cc.	5.5 "	= 0.911 " hourly 0.036 " per sq. cm.
	Reset			
Dec. 15	9:00 a.m.– 2:00 p.m	4.0 "	5.0 "	= 0.800 " hourly 0.032 " per sq. cm
Dec 16	3:30 p.m.	7.0 "	9.0 "	= 0.777 " hourly 0.031 " per sq. cm.
Dec. 17	9:00 a.m.– 3:00 p.m.	3.8 "	6.0 "	= 0.633 " hourly 0.022 " per sq. cm.

No. 7

Dec. 11	Section from same internode as No. 6. 9 layers of wood, 11 cm. long, 11.0 mm. diam. Free surface = 29 sq. cm.			
Dec. 12	9 00 a.m.	Reset.		
	4:00 p m.	8.6 cc.	7.0 hrs.	= 1.228 cc. hourly 0.042 " per sq. cm.
Dec. 13	2:00 "	7.6 "	5.5 "	= 1.381 " hourly 0.047 " per sq. cm.
Dec. 14	8:00 "	7.5 "	6.0 "	= 1.250 " hourly 0.043 " per sq. cm.
	8:30 a.m.	Reset		
	2:00 p m.	7.6 "	5.5	= 1.381 " hourly 0.047 " per sq. cm.
Dec. 15	9:00 a m 2:00 p.m.	7.8 "	5.0 "	= 1.360 " hourly 0.047 " per sq. cm.
Dec. 16	3:30 p.m.	13.0 "	7.0 "	= 1.860 " hourly 0.064 " per sq. cm.
Dec. 17	9:00 a.m. 3:00 p.m.	8.0 "	6.0 "	= 1.33 " hourly 0.046 " per sq. cm.

No. 8

Dec. 11	Section from internode, similar to No. 6. 7 layers of wood, 10 cm. long, 12.0 mm. diameter. Free surface = 35 sq. cm.			
Dec. 12	9:00 a.m.	Reset		
	4.00 p.m.	3.8 cc. in	7.0 hrs.	= 0.543 cc. hourly 0.016 " per sq. cm.

Dec. 13	9:30 a.m.	Reset		
	8:00 p.m.	5.8 cc. in	10.5 hrs.	= 0.552 cc. hourly
				0.019 " per sq. cm.
Dec. 15	9:00 a.m.	Reset		
	2:00 p.m.	3.0 "	5.0 "	= 0.600 " hourly
				0.021 " per sq. cm.
Dec. 16	3:30 p.m.	5.2 "	9.0 "	= 0.577 " hourly
				0.021 " per sq. cm.
Dec. 17	9:00 a.m.			
	3:00 p.m.	3.0 "	6.0 "	= 0.500 " hourly
				0.018 " per sq. cm.

No. 9

Dec. 11	Same internode as No. 10. 8 layers of wood, section 11 cm. long, 11.0 mm. diam. Free surface = 29 sq. cm.			
Dec. 12	9:00 a.m.	Reset		
	4:00 p.m.	3.8 cc.	7.0 hrs	= 0.543 cc. hourly
				0.019 " per sq. cm.
Dec. 13	8:30 a.m.	Reset		
	8:00 p.m.	6.0 "	11.5 "	= 0.522 " hourly
				0.018 " per sq. cm.
Dec. 15	9:00 a.m.	Reset		
	2:00 p.m.	3.0 "	5.0 "	= 0.600 " hourly
				0.021 " per sq. cm.
Dec. 16	6:30 a.m.	Reset		
	3:30 p.m.	4.5 "	9.0 "	= 0.500 " hourly
				0.017 " per sq. cm.
Dec. 17	9:00 a.m.	Reset		
	3:00 p.m.	3.0 "	6.0 "	= 0.500 " hourly
				0.017 " per sq. cm.

No. 10

Dec. 11	Section 10.5 cm. long, 7 layers of wood, 10.5 mm. diam. Free surface = 27 sq. cm.			
Dec. 12	9:00 a.m.	Reset		
	4:00 p.m.	4.0 cc.	7.0 hrs.	= 0.555 cc. hourly
				0.021 " per sq. cm.
Dec. 13	8:30 a.m.	Reset		
	8:00 p.m.	6.2 "	10.5 "	= 0.573 " hourly
				0.021 " per sq. cm.
Dec. 15	9.00 a.m.	Reset		
	2:00 p.m.	2.3 "	5.0 "	= 0.460 " hourly
				0.017 " per sq. cm.
Dec. 16	6:30 a.m.	Reset		
	3:30 p.m.	5.4 "	9.0 "	= 0.600 " hourly
				0.022 " per sq. cm.
Dec. 17	9:00 a.m.	Reset		
	3:00 p.m.	4.0 "	6.0 "	= 0.666 " hourly
				0.025 " per sq. cm.

Another series of tests were made with young branches, some of which still retained leaves and with the cambium in an active condition, April 21–28, 1933. All were from internodes

3 or 4 years old. Two, Nos. 15 and 16, retained some of the original leaves on their surfaces. Diameters ranged from 9.5 to 10.5 mm. and the lengths ranged from 80 to 100 mm. The areas of the free surfaces through which air might pass into the sections ranged from 27 to 44 sq. mm. Suction was maintained at 98–100 mm. Hg during the tests.

Section No. 11, with a surface of 33 sq. cm., gave rates of 0.024, 0.024, 0.026, 0.023, 0.021, and 0.033 cc. hourly per sq. cm.

The rates of infiltration in No. 14 were 0.007, 0.010, 0.012, 0.012, 0.013 and 0.016 cc. per sq. cm. Control gauge readings of 95, 96, 94, 93, and 93 mm. were recorded.

No. 14 was cut from the basal part of an internode in its 4th year. Some green leaves were retained on the distal part of the internode. The layers of the section were thicker than in Nos. 11, 12, and 13, the average diameter being 10.5 mm. Rates of infiltration of 0.026, 0.032, 0.035 and 0.042 cc. hourly per sq. cm. were noted.

Nos. 15 and 16 cut from internodes in their 4th year presented a singular case. No. 15 retained about 15 leaves, was 10 mm. in diameter and was mounted to leave a free surface of 27 sq. cm. The first extraction yielded 0.5 cc. in 6 hours which was at the rate of 0.003 cc. hourly per sq. cm. A similar extraction on the following day gave a rate of 0.002 cc. hourly per sq. cm. On the third day the rate was but 0.001 cc., while a final test for 50 hours showed but 0.0007 cc. hourly per sq. cm. The penetrability of the section was plainly diminishing.

Section No. 16, 9.5 mm. in diameter, and 105 mm. in length, was mounted to leave a free surface of 44 sq. cm. This section was cut from an internode in its 4th year which retained a majority of its leaves. The section as mounted carried 102 green leaves and had borne 30 or 40 more the previous year.

The first 4 hour test showed an hourly rate of 0.016 cc. per sq. cm. The extraction upon which this rate was calculated included air in the tracheids. The rate during a 6 hour period

on the following day was 0.005 cc. hourly per sq. cm.; the next day the rate was 0.004 cc., then 0.003 cc., and 0.002 cc. in a final 50 hour test.

The control gauge of No. 15 read about 100 mm. during the greater part of the time, and that of No. 16 over 90 mm. It was thus evident that a tract extending the length of the stem was evacuated to a pressure near that of the column in the suction apparatus. The penetration of air was blocked by some feature not yet clearly determined. Some additional leafy sections were tested. When the section was dismounted a week after being cut, the leaves appeared cool, moist and not flaccid. But little resin was found. The autumnal wood, however, seemed dense and close.

Two sections were cut from leafy internodes of separate trees in their fourth year on May 3rd. The rate of infiltration was very low in both and in general agreement with the action of Nos. 15 and 16 described above.

No. 17 was taken from an internode in its fourth year, on a branch of a tree about 8 years old. With a diameter of 8 mm. and a length of 120 mm. it was mounted to present a free surface of 30 sq. cm. The section carried 111 leaves.

The first extraction, May 2nd, gave a rate of 0.06 cc. hourly per sq. cm. This of course included the air in the section. The second extraction running 22 hours at 100 mm. Hg gave an infiltration rate of but 0.0033 hourly per sq. cm. Extended 20–29 hours the rate was 0.0031 cc.; to 48 hours it was 0.0027 cc. hourly per sq. cm. With a suction maintained at 95 to 100 mm. Hg the control gauge at the free end stood between 94 and 96 mm. Hg. During this final period of 68 hours a suction of 100 mm. Hg had drawn 5.5 cc. of air into and out of the section, or 1.8 cc. per sq. cm.

No. 18 run at the same time yielded but 1.2 cc. in 68 hours. This section was taken from an internode in its 4th year on another tree. Its length was 80 mm. and diameter 8 mm. It was mounted to present a free surface of 21 sq. cm. The initial extraction gave a rate of 0.045 cc. Following the rates ran 0.002, 0.0016, 0.001 cc. hourly per sq. cm. The total

extraction for the 6.8 hour period was 1.2 cc., 0.0009 cc. hourly per sq. cm., or less than 0.00 cc. per sq. cm. for the entire period. The control gauge showed from 95 to 97 mm. suction at the free end during the entire period of the extraction.

No. 19 was taken from an internode that had cast its leaves the previous year. The initial rate was 0.014 cc. hourly per sq. cm., followed by a drop to 0.0023 cc.

No. 20, also from an internode which cast its leaves the previous year, showed an initial rate of 0.016 cc. hourly which fell to 0.003, 0.007 cc. hourly per sq. cm.

Finally a section which had cast its leaves two years before was tested and found to show the low rate of penetrability of leafy internodes. At the same time (mid-May) another section which had cast its leaves three years before was tested and found to show the higher rate of older internodes. At this stage of the experimentation it would seem that the low penetrability of internodes persists through the second season after the leaves have been cast.

These exploratory tests can not be taken to show that active cambium with the resultant increased thickness of the layer of living cells is less penetrable than the thinner layer of the resting condition. The possible blocking effects of resin may vary greatly.

Ventilation in Roots

While the cambium of roots is in a layer not widely different from that prevalent in stems, the accompanying anatomical conditions are distinctly different.

Search was made until long roots running near the surface were found, then these were taken up without damage and cut into sections 7–10 cm. long. Roots not exceeding 12 cm. in diameter were used exclusively. Such roots had loose bark, coming away in thin flakes, and were soft and watery. The woody cylinder was bared as in stems, for a short section at one end, which was connected by a short section of pressure

tubing with the side outlet of a special burette. The free end was sealed with a mixture of vaseline, paraffine and beeswax.

The hourly rates per square cm. at which air was drawn through the sections into the burette in 6 specimens on successive days is given below:

No. 1.	0.070 cc.	0.130	0.150	0.200		
2.	0.040	0.160	0.300			
3.	0.050	0.070	0.120			
4.	0.035	0.210	0.220	0.230	0.310	0.340
5.	0.050	0.150	0.160	0.290	0.300	0.460
6.		0.150	0.150	0.150		

A long root near surface from pine tree No. 1 (Dendrographic series) was taken up February 16th. The diameter varied from 11 to 12 mm. Sections varied from 45 to 80 mm. in length. The sections were fitted to the burettes between 8:50 and 9:15 a.m. February 16th, within a half hour after being taken up. The rates were as follows, in periods of a few hours on successive days:

No. 10.	0.0080	0.0140	0.0200	0.0240	0.0250
11.	0.0170	0.0110	0.0900	0.0130	0.0140
12.	0.0050		0.0030		
13.	0.0040	0.0035	0.0110		0.0160
14.	0.0150				

Another root of the same tree which was traced to a distance of 17 meters from the base of the trunk bore a secondary root from which sections 9 to 11 mm. in diameter, which were prepared to leave 65 to 80 mm. in length free, were cut on March 10th.

The ends left free and customarily sealed with wax were connected by a short section of heavy rubber tubing with a short piece of glass tubing with a capillary base, standing in a small vessel filled with mercury. Such an arrangement acted as a control of the seal, and also registered the amount of suction transmitted longitudinally through the section. After the air above the burette was displaced by Hg and the level

of the Hg receiver was lowered, the transmitted suction pulled up a column of Hg in the capillary bore giving a measure of the suction.

It was seen that the capillary column was never more than 90 mm. in height with a suction of 100 mm. through the burette, and that it might be as low as 80 mm., a fact of course resulting from the constant infiltration of air through the surface.

In some cases the capillary manometer rose very slowly, not reaching the above levels for two or three hours. In other cases the maximum might be reached in 15 or 20 minutes. The rates of infiltration varied widely in these sections.

In No. 19 the rate ran 0.008, 0.008, 0.100, and 0.050 cc. hourly per square cm.

In No. 14 the rate ran 0.015, 0.037, 0.030, 0.035, 0.025 cc. hourly per square cm.

No. 15 displayed rates of 0.036, 0.036, 0.017, 0.016, and at last 0.250, 0.160 cc. hourly per sq. cm.

A maximum penetrability was displayed by No. 18, in which the capillary manometer was pulled up to 85 mm. by a suction of 100 mm. in 15 minutes. The rate of infiltration began at 0.130 and mounted to 0.400 cc. hourly per square cm. That this represented entrance of air through the surface and not faulty fittings was demonstrated by the action of the section when the free surface was coated with shellac. A suction of 90 mm. Hg at the end of 5 hours was accompanied by the expansion of gases in the stem to make about 0.200 cc. in the burette while the capillary manometer at the other end of the section stood at 80 mm.

No. 17 displayed rates of 0.040, 0.040, 0.080, 0.080, and 0.180 cc. hourly per square cm. of free surface. About half of the free surface was now coated with shellac. The rate during the first hour was 0.110 cc. per sq. cm. for the exposed surface.

No. 16 also displayed rapid communication of suction through its length, the capillary manometer rising to 95 mm.

within ten minutes after the application of 100 mm. Hg suction. Rates of 0.130, 0.160, and 0.440 cc. hourly per sq. cm. were displayed. Half of the section was now coated with shellac. During the following 2 hours the rate was 0.220 cc. hourly for the exposed surface, or as with No. 17 about the same rate as before for the actual free surface.

The penetrability of sections of roots is seen to increase within a day or two presumably due to desiccation under laboratory conditions. The rate varied widely, reaching higher maxima than was shown by any sections of stems.

Sequoia sempervirens
(Redwood)

The series of sections was taken from the internodes of branches of redwood on which the leaves had matured. In some cases they remained in place, dead and dry; in others all had been cast off. All sections showed at least six layers of wood, indicating an activity of the leaves persistent through as many years.

A lot of 7 sections mounted for testing on June 7, 1933, gave the following results:

No. 2

From same internode as No. 3. Section 9.0 mm. in diam.; free surface = 8 cm. long with an area of 23 sq. cm. Mounted June 7th.

June 8	3.0 cc.	8.0 hrs.	= 0.375 cc. hourly
			0.016 " per sq. cm.
June 9	2.6 "	8.0 "	= 0.325 " hourly
			0.014 " per sq. cm.
June 17	1.4 "	3.5 "	= 0.400 " hourly
			0.017 " per sq. cm.
June 19	3.9 "	9.0 "	= 0.433 " hourly
			0.019 " per sq. cm.
June 21	1.6 "	3.5 "	= 0.457 " hourly
			0.019 " per sq. cm.

No. 3

June 7	Section 9.5 mm in diam. Free surface = 7.5 cm. long, with an area of 22 sq. cm. Initial extraction 0.8 cc. in 2.3 hrs. at a rate 0.035 cc. hourly, 0.0016 cc. per sq. cm.		
June 8	2.0 cc.	8.0 hrs.	= 0.250 cc. hourly
			0.011 " per sq. cm.
June 9	1.3 "	8.0 "	= 0.163 " hourly
			0.008 " per sq. cm.

June 17	0.9 cc.	3.5 hrs.	=	0.257 cc.	hourly
				0.012 "	per sq. cm.
June 19	1.5 "	9.0 "	=	0.167 "	hourly
				0.008 "	per sq. cm.

No. 4

Section 10.0 mm. diam., free surface = 7 cm long, area 22 sq. cm.

June 7	Trial extraction				
June 8	1.8 cc.	8.0 hrs.	=	0.225 cc.	hourly
				0.010 "	per sq. cm.
June 9	1.8 "	8.0 "	=	0.225 "	hourly
				0.012 "	per sq. cm.
June 10	1.6 "	9.5 "	=	0.168 "	hourly
				0.008 "	per sq. cm.
June 19	1.4 "	9.0 "	=	0.156 "	hourly
				0.007 "	per sq. cm.

No. 5

Section 10.0 mm. diam., 8.5 cm. long, free surface = 27 sq. cm.

June 7	5:00 p.m. Mounted Reset					
June 8	9:00 a.m.	3.0 cc.	7.0 hrs.	=	0.430 cc.	hourly
					0.016 "	per sq. cm.
June 9		2.5 "	8.0 "	=	0.315 "	hourly
					0.011 "	per sq. cm.
June 17		1.2 "	3.5 "	=	0.343 "	hourly
					0.013 "	per sq. cm.

No. 6

Section 11.0 mm. diam., 9.5 cm. long, free surface = 39 sq. cm.

June 8	0.4 cc.	8.0 hrs.	=	0.050 cc.	hourly
				0.001 "	per sq. cm.

June 10 Burette not emptied from previous 105 hours. Rate for entire period = 0.040 cc. hourly, 0.001 cc. per sq. cm.

Salix lasiolepis

(Willow)

Nov. 18, 1932. Section 1 to 5 cut from long branch of original rapid growth.

No. 1

10.0 mm. diam. Vol. = 9 cc. Free surface = 9.5 cm. long = 30 sq. cm.

Nov. 21	8:00 a.m.	2.8 cc.	45.0 hrs.	=	0.062 cc.	hourly
					0.002 "	per sq. cm.
Nov. 23	8:00 a.m.	2.8 "	48.0 "	=	0.060 "	hourly
					0.002 "	per sq. cm.
Nov. 25	4:00 p.m.	4.0 "	56.0 "	=	0.071 "	hourly
					0.002 "	per sq. cm.
Nov. 27	8:30 a.m.	2.8 "	40.5 "	=	0.069 "	hourly
					0.002 "	per sq. cm.

Nov. 29	3:30 p.m.	7.5 cc.	55.0 hrs.	= 0.134 cc. hourly
				0.004 " per sq. cm.
Dec. 1	4:00 p.m.	3.1 "	48.5 "	= 0.064 " hourly
				0.002 " per sq. cm.

No. 2

Nov. 18, 1932. Length = 17 cm. Diam. = 10.5 mm. Vol. = 15 cc. Free surface = 14 cm long = 33 sq. cm.

Nov. 19	8:00 a.m.	Down to 90 mm.		
		5.3 cc.	24.0 hrs.	= 0.221 cc. hourly
				0.007 " per sq. cm.
Nov. 20	11.00 "	Down to 80 mm.		
		7.0 cc.	27.0 "	= 0.222 " hourly
				0.007 " per sq. cm.
Nov. 21	7:30 p.m.	5.2 "	23.0 "	= 0.226 " hourly
				0.007 " per sq. cm.
Nov. 23	8:30 a.m.	7.0 "	25.0 "	= 0.280 " hourly
				0.008 " per sq. cm.
Nov. 24	8:30 "	7.0 "	24.0 "	= 0.290 " hourly
				0.009 " per sq. cm.

No. 3

Diam. = 11.0 mm. Vol. = 12 cc. Free surface = 11 cm. long = 38 sq. cm.

Nov. 18	First attached to burette.			
Nov. 19	Refitted.			
Nov. 20	9:10 a.m.	4.2 cc.	22.0 hrs.	= 0.191 cc. hourly
				0.005 " per sq. cm.
Nov. 23	8:00 "	5.0 "	48.0 "	= 0.104 " hourly
				0.003 " per sq. cm.
Nov. 24	8:30 "	2.1 "	24.0 "	= 0.087 " hourly
				0.002 " per sq. cm.
Nov. 25	4:00 p.m.	4.3 "	36.0 "	= 0.119 " hourly
				0.003 " per sq. cm.
Nov. 27	8:30 a.m.	5.0 "	40.5 "	= 0.123 " hourly
				0.003 " per sq. cm.
Nov. 29	2:30 p.m.	5.0 "	30.0 "	= 0.166 " hourly
				0.004 " per sq. cm.
Dec. 1	4:00 "	4.0 "	25.5 "	= 0.157 " hourly
				0.004 " per sq. cm.

No. 4

Nov. 18 Section 15 cm. long. Diam. = 12.5 mm. Vol. = 12 cc. Free surface = 43 sq. cm.

Operations for first 3 days faulty.

Nov. 20	9:00 a.m.	Reset at 100 mm.		
Nov. 21	8:00 "	6.2 cc.	23.0 hrs.	= 0.270 cc. hourly
				0.006 " per sq. cm.
	8:00 p.m.	3.5 "	12.0 "	= 0.290 " hourly
				0.006 " per sq. cm.
Nov. 22	7:30 a.m.	Reset		
	7:30 p.m.	4.5 cc.	12.0 "	= 0.375 " hourly
				0.008 " per sq. cm.

Nov. 26	8:00 a.m.	4.6 cc.	16.0 hrs.	= 0.287 cc. hourly
				0.006 " per sq. cm.
Nov. 27	8:30 "	7.0 "	24.5 "	= 0.280 " hourly
				0.006 " per sq. cm.
Dec. 1	8.00 "	3.5 "	16.5 "	= 0.212 " hourly
				0.005 " per sq. cm.

No. 5

Nov. 18, 1932. Length = 17 cm. Diam. = 11.0 mm. Vol. = 16 cc. Free surface = 14 cm. long = 48 sq. cm.

	8:15 a.m.	Set at 100 mm.		
Nov. 19	8:00 "	3.5 cc.	24.0 hrs.	= 0.146 cc. hourly
				0.003 " per sq. cm.
Nov. 20	9:00 "	4.0 "	23.5 "	= 0.170 " hourly
				0.003 " per sq. cm.
Nov. 22	8.00 "	4.2 "	24.0 "	= 0.175 " hourly
				0.003 " per sq. cm.
Nov. 23	8:30 "	3.8 "	24.0 "	= 0.158 " hourly
				0.003 " per sq. cm.
Nov. 24	8.30 "	3.8 "	24.0 "	= 0.158 " hourly
				0.003 " per sq. cm.
Nov. 25	4.00 p.m.	5.0 "	31.5 "	= 0.160 " hourly
				0.003 " per sq. cm.
Nov. 30	2:30 "	5.0 "	30.0 "	= 0.166 " hourly
				0.003 " per sq. cm.
Dec. 1	4.00 "	3.8 "	25.5 "	= 0.150 " hourly
				0.003 " per sq. cm.

No. 6

July 7, 1932. 10.00 a.m. Section of young shoot formed by rapid growth 11.0 mm. in diam., 14 cm. long, vol. = 42 cc., free surface = 35 sq. cm.

The rate for 83 hours ending July 10th at 9:00 p.m. at suction from 150 down to 110 mm. was 0.001 cc. hourly per sq. cm.

The outermost and perhaps previously water-sealed layer had been opened by this time as the rate was 0.006 cc. during the next 10 hour period, with suction between 100 and 80 mm. Rates on the days following were 0.005 cc., 0.006 cc., 0.007 cc., with suction varying from 100 down to 60 mm. Hg. On July 15th an increased penetrability under suction near 100 mm. Hg was observed. Rates of 0.01 cc., 0.013 cc., 0.013 cc., 0.026 cc. and 0.017 cc. per sq. cm. hourly were recorded.

Finally, on August 6th, thirty days after the preparation was set up, the rate rose to 0.040 cc. per sq. cm. hourly, indicating a penetrability about forty times the initial rate.

Quercus hypoleuca
(Desert oak)

Sept. 13, 1932. Noon. Branch several years old cut into several sections and fitted to extraction apparatus.

No. 1

Section 10 cm. long. Diam. = 14.0 mm. Vol. = 15 cc. Free surface = 35 sq. cm.

Sept. 14	1:00 a.m.	2.8 cc.	23.0 hrs.	= 1.217 cc. hourly	
				0.147 " per sq. cm.	
	4:00 p.m.	3.7 "	5.0 "	= 0.740 " hourly	
				0.021 " per sq cm.	
Sept. 15	8:00 a.m.	Reset			
	11:00 "	4.3 "	3.0 "	= 1.433 " hourly	
				0.040 " per sq. cm.	

No. 2

Sept. 13	Noon. Section 13 cm. long, 12.0 mm. in diam. Vol. = 15 cc. Free surface = 33 sq. cm.			
Sept. 14	8:00 a.m.	Reset		
	11:00 "	6.0 cc.	3.0 hrs.	= 2.000 cc. hourly
				0.060 " per sq. cm.
Sept. 15	8:00 "	Reset		
	11:00 "	5.0 "	3.0 "	= 1 666 " hourly
				0.050 " per sq. cm.

No. 3

Sept. 13	Noon. Section 13.5 cm. long, 12.0 mm. in diam. Vol. = 15 cc. Free surface = 46 sq. cm.			
Sept. 14	8:00 a.m.	Reset		
	11:00 "	3.2 cc.	3.0 hrs.	= 1.070 cc. hourly
				0.023 " per sq. cm.
	4:00 p.m.	4.1 "	5.0 "	= 0.820 " hourly
				0.018 " per sq. cm.
Sept. 15	8:00 a.m.	Reset		
	11:00 "	3.1 "	3.0 "	= 1.033 " hourly
				0.022 " per sq. cm.

No. 4

Sept. 13	Noon. Section 14 cm. long, 9.0 mm. diam. Vol. = 9 cc. Free surface = 34 sq. cm.			
Sept. 14	8:00 a.m.	Reset		
	11:00 "	2.2 c.c	3 0 hrs.	= 0.733 cc. hourly
				0.018 " per sq. cm.
Sept. 15	8:00 a.m.	Reset		
	11:00 "	2.0 "	3.0 "	= 0.666 " hourly
				0.019 " per sq. cm.

No. 5

Sept. 13 Noon. Section 14 cm. long, 10 mm. diam. Vol. = 11 cc. Free surface = 38 sq. cm.

Sept. 14	8:00 a.m.	Reset		
	11:00 "	2.2 cc	[illegible]	= [illegible] cc. [illegible]
				[illegible] " per sq. cm.
	4.00 p.m.	2.3 "	[illegible]	= [illegible] " [illegible]
				[illegible]12 " [illegible]
Sept. 15	8:00 a.m.	Reset		
	11:00 "	2.5 "	[illegible]	= [illegible] " [illegible]
				[illegible]21 " per [illegible]

Quercus agrifolia
(California liveoak)

The penetrability of branches of this California live oak was tested in September 1932. Such a wide range of variation was found as to raise doubts as to the defects in the apparatus. Following the development of special barettes and improvement of methods further tests were made in May 1933. The results denoted that penetrability might vary with the age of the branch, and with the condition of the lenticels.

The matter of anatomical changes in the bark, and in the cambium, has not yet been traced or defined. It is known, however, that the cambium is active at this time. The lenticels are much more apparent in the first two or three years of the development of internodes, during which period they are a vivid green. The longitudinal communications are so free and open that when the mercury receiver is set at a level to give a suction of 100 mm., the column in the control gauge rises to 95 and even higher within 1 to 3 seconds. That it does not go up to 100 is due to radial infiltration which begins at once.

Nos. 1 and 2 also bore 3 and 4 latent buds, and showed many active or open lenticels on the smooth green surfaces. No. 2 was 9 mm. in diameter and 90 mm. long, presenting 26 sq. cm. of green surface when mounted. The infiltration rates were 0.080, 0.089, 0.077, and 0.072 cc. hourly per square cm. The resistance was shown by a column of 12 mm. Hg in the control gauge after 24 hours.

Section No. 1 was 10 mm. in diameter and 90 mm. long, being mounted to present a free surface of 288 sq. cm. Rates of infiltration as follows were observed: 0.090, 0.077, 0.086,

0.075, and 0.073 cc. hourly per sq. cm. A resistance of 10 mm. Hg after 24 hours was recorded.

Section No. 3 offered a vivid contrast to No. 4. This was a vivid green, bore two latent buds and showed many lenticels, which stood up from the surface. After some tests the buds were sealed but no influence on the rates was observed. The penetrability was indicated by the fact that when the extraction was allowed to "run down" by allowing the level of the mercury in the burette and in the receiver to approximate each other, an equilibrium was reached at a difference of 12 mm. 24 hours later.

The rate of infiltration under a suction of 100 mm. Hg ran as follows: 0.016, 0.017, 0.019 0.020, 0.021, 0.018, 0.016 and 0.016 cc. hourly per sq. cm.

Section 4, cut May 2nd from an internode with a grayish epidermis, no buds, lenticels inconspicuous and probably nearly blocked, was 75 mm. long, 10 mm. in diameter, and presented a free surface of 24 sq. cm. after being mounted. The first extraction for 5 hours gave an estimated rate of 0.031 cc. hourly per sq. cm., later measurements of 0.050, 0.045, and 0.042 cc. hourly per sq. cm.

At the end the extraction apparatus was allowed to "run down" with the result that a column 30 mm. in height was held in the control gauge.

General

All of the tests described in the previous pages were made in such manner that the initial suction of 100 mm. Hg was not allowed to fall below 95 mm. in the course of any test. Probably such differences in pressure are not exhibited for prolonged periods in tree-trunks. Any differences between internal and external pressures may be due to three main causes, variations in atmospheric pressure as shown by the barometer, liberation of carbon dioxide from living elements and from maturing woody walls and changes in volume of the hydrostatic system following varying tension due to transpiration.

These factors would at times cause an outward streaming of gases from the interior and at other times an inflow from the

atmosphere. In order to determine the amount of pressure necessary to initiate a streaming movement through the narrow and tortuous passages leading out from the wood across the cambium, or rather the point at which diminishing suction would cease to draw air into a stem, the columns of mercury in the extraction apparatus attached to five sections of *Quercus hypoleuca* were allowed to run down, and the level at which extraction ceased was noted. The results are given below.

LEVEL OF MERCURY AT WHICH STREAMING OF AIR INTO STEMS CEASED

	No. 1	2	3	4	5
Sept. 19th, 8 a.m.	5 mm.	8 mm.	6 mm.	16 mm.	16 mm.
20th, "	5	8	5	12	14
21st, "	5	7	5	12	14
22nd, "	5	8	5	10	14

A variation from 5 to 14 mm. Hg in the minimum amount of suction causing a flow in this oak was found.

In the oak radial communication through the spaces in the multiserial rays is capacious and internal suction is quickly transmitted to the region of the cambium.

In the willow the hydrostatic system occupies the outer half of every seasonal layer, making a watery cylinder, passages through which streaming may take place are much restricted. These have the mechanical arrangement of a series of enclosing tubes. The rays from the medulla interrupt the walls of every tube out to the cambium, but as these rays are a single plate of living cells the intercellular passages are very meager and indefinite.

Suction applied to the end of a stem extracts gases from every seasonal layer. The gas in the outermost layer occupies the spring wood or the innermost part of the layer. Consequently the gases are separated from the cambium layer by a water-filled layer of wood-cells a millimeter or more in thickness.[1]

[1] See figures 11, p. 35, 15, p. 47, 17, p. 57, Publ. No. 397, Carnegie Inst. of Wash., 1929.

In any experiment with Salix therefore a low rate of infiltration may be expected initially and to continue until the watery layers are depleted.

In the pine and redwood three or four outermost layers of wood are occupied by sap, and although traversed by rays this cylinder doubtless offers some restriction to the outward or inward streaming of air. If now the rates of flow under a difference of pressure into stems of the species tested be summarized it will be seen that in the Monterey pine the rate varied from 0.004 to 0.044 cc. hourly per sq. cm. in stems 7 to 9 years old, being less in younger stems and also in small roots.

In the redwood the flow was 0.010 to 0.019 cc. hourly per sq. cm., it being noted that the rate did not increase after a few days as in the pine.

The flow in the willow varied between 0.002 and 0.009 cc. hourly per sq. cm. and did not increase in sections attached to the extraction apparatus for 30 days. The rate in the California live oak varied between 0.016 and 0.090 cc. hourly per sq. cm. The rate in *Q. hypoleuca*, an Arizona desert oak, was between 0.012 and 0.060 cc. hourly per sq. cm.

The lowest rate was exhibited by the willow and the highest by the California live oak. The greatest variation was found in the Monterey pine and the least in the redwood. The relative facility of movements of air into the trunks of these five trees may be expressed by the mean between the maximum and minimum as follows:

Salix lasiolepis (Willow)	5
Sequoia sempervirens (Coast redwood)	15
Pinus radiata (Monterey pine)	24
Quercus hypoleuca (Arizona desert oak)	36
Q. agrifolia (California live oak)	53

An examination of the probability that the proportion of carbon dioxide inside the tree, or more broadly speaking the difference in composition between the pneumatic systems of trees and the outside air would be correlated with the rate of flow, showed that no such correlation exists. As for example, the highest mean rates of flow and the highest

proportions of carbon dioxide were found in the California live oak.

The dominant feature is doubtless that of the rate of liberation of carbon dioxide in the interior of the trunks. It is to be recalled that when drenching rains saturated the cortex and perhaps closed the gas conduits across the cambium layers the proportion of carbon dioxide in trunks was very high.

Finally, it is to be noted that no correction was made for barometric pressure. Thus with a high barometer which might be sufficient to cause an inflow of gases, a suction of 100 mm. Hg would cause a more rapid rate of penetration than with a low barometer tending to withdraw air from stems. This correction may be taken into account in subsequent observations.

Summary

1. Apparatus and an adequate method of measurement of the rate of streaming of atmospheric gases into the interior of living sections of woody stems have been developed.

2. Tests were made on stems 5 to 10 years old with an equivalent number of shells or cylinders of wood (annual rings).

3. Differences in pressure of 95 to 100 mm. Hg were maintained by cisterns of mercury and a levelling adjustment.

4. Such pressures caused streaming of air into the stems of Monterey pine, 0.004 to 0.044, Coast redwood, 0.010 to 0.019, willow, 0.002 to 0.009, California live oak, 0.016 to 0.090, and Arizona desert oak, 0.012 to 0.060 cc. per sq. cm. hourly.

5. These results establish the presence of passages from the pneumatic system of trees across the cambium layer which are too small to allow streaming movements of watery solutions.

6. The amount of suction necessary to initiate or maintain a flow of atmospheric gases through these ducts varies from 5 to 30 mm. Hg in various trees.

7. In some cases, as in Salix, sap-filled layers of wood were taken to affect the rate of streaming.

8. Variations in barometric pressure, in tensions of the meshwork of sap conduits, and liberation of carbon dioxide from living cells and woody walls are factors which may set up differences in pressure and initiate streaming movements.

9. The streaming movements of gases through the cambium outwardly or inwardly have the effect of tending to equalize the pressure and composition of the pneumatic system and the outside air, thus constituting a means of ventilation. The pneumatic system, estimated at barometric pressure may have a volume equivalent to 20 to 40 per cent of that of the entire trunk, and relative changes in composition by ventilation would be least in large trunks.

10. It is to be noted that rates of flow of young stems were measured, while determinations of the composition of the gases of pneumatic systems were made upon samples extracted from large or old trunks. The cambium layer would be identical in mechanical features with that of young stems, but the other features of the old trunks might modify the rate of flow. The determination of rates of flow in large or old trunks would require different methods from those described in the present paper.

GROWTH DURING ADULT LIFE

ALEŠ HRDLIČKA

(Read April 25, 1936)

Abstract

A very large amount of attention, particularly in this country, has been given to studies of growth in the human body and its parts, growth from birth to the age which is generally accepted as that of maturity. This age is generally close to 24 in the white man, 20–22 in the white woman. After those ages have been reached and all the epiphyses united with their bones, all further growth was believed to have ceased.

A few workers in the course of time found facts indicating that slight growth in stature and in the head, face, and some other parts, may proceed beyond the reach of maturity, but they were soon forgotten.

The first to present some evidence in this connection were the Frenchman Parchappe and the Belgian Quetelet, just one hundred years ago (1836). In the century since relevant data accumulated as to stature, but little else was done until 1899, when a German anatomist, W. Pfitzner, confirmed the early claims and brought considerable further evidence on the subject. Even that work, however, remained almost unnoticed.

Since 1898 and especially 1910, careful and extensive anthropometric studies on the American Indian, and on the old-American Whites, in which the age factor received due attention, not only corroborated the previous findings, but also extended the scope of the inquiry. The results were published in 1925 (*The Old Americans*) and 1936 (*The Pueblos and other Indians*); and they were supplemented in 1935 by Russian data on four large groups of the Soviet population.

All this evidence sustains the main fact, which is that growth does not completely or in all individuals cease by 22–24 years, but that, on the average, it proceeds slowly in some features to the fourth decade, in others to the fifth, and in a few even later. Elements included are stature, various head and face diameters, the chest, hands and feet, and especially the mouth, nose and ears.

In some characters, such as the stature and head size, the growth when senility begins to set in is followed by gradual diminution; in parts like the ear, nose, and mouth however, slow increase in size proceeds into old age and there is no decrease.

In all the above, as in every other human function or manifestation, there is considerable individual variation.

There is a universal notion that when the adult stage of life has been reached, all growth of the human body and its parts, except in bulkiness, has been accomplished and henceforth ceases. The very definition of an "adult" is that of "a person grown to full size and strength." The purpose of this paper is to show that, while such a concept suffices in general, scientifically speaking the view is largely erroneous.

That the notion remained so long unchallenged was due

to the difficulties and hence scarcity of observations on the adults. A large amount of work has been done in studies on the child, on the adolescent, and on the sub-adult to young-adult recruit; another collectively great effort has been expended in studying the grownups from the point of view of race and type; but the changes that may be taking place in the human frame and organs between the time the "adult" stage has been reached and marked senile changes set in, have received little attention.

The subject which I approach today has an exceptionally interesting history. It is just 100 years ago, in the very infancy of anthropometry, that simultaneously there appear two works, one in France, one in Belgium, pointing to the fact that all growth in the human body does not stop with the reach of the adult stage or maturity, but goes on sensibly until at least the fourth decade of life and in some respects perhaps even further. Then for over 30 years the matter lies nearly dormant; during the next 60 it receives but three contributions of value, two of which are limited to stature; and only during the last ten years the study broadens and the main facts tend to become established. Meanwhile a vast amount of measurements have been taken on different people and published with little if any regard to the age factor, much of which work will have to be relegated to the preliminary.

The two initial contributions that touched on the subject were both published in 1836, one in Paris, one in Brussells. One was by Parchappe,[1] an outstanding student of the brain, whose work led him to the conclusion that the volume of the head in the French people to whom his observations applied, was not stable during maturity, but kept on increasing appreciably, on the average, up to as late as 50.

The other publication was that of Quetelet, on *Man and the Development of his Faculties*,[2] and in this the author reported,[3] on the basis of measurements of 900 men of Brussells,

[1] Parchappe, *Recherches sur l'encéphale*, Volume I, Du volume de la tête et de l'encéphale [illegible] Paris, 1836.

[2] Quetelet, A., [illegible] 2 vols. in 16 mo., Brussells, 1836.

300 each of 19, 25 and 30 years of age, that growth in stature did not terminate at 19 as was then believed, and in some not even at 25.[1]

Corroborative of Quetelet's claims were the data published in 1841 by Lélut, in his study *Sur la taille moyenne de l'homme en France* (Paris). The measurements of stature on five series of 400 each of male "détenus," showed the maximum not to have been reached before the age-group of 30–50.

In 1869 and 1875 appear in print the huge American statistics on the soldiers of the Civil War, by Gould and Baxter,[2] and with all their defects they furnish unquestionable evidence that stature, on the average, keeps on increasing slightly long after what is generally regarded as the adult stage is reached; and the same phenomenon is more or less evident also in the American Negro and Indian.

In 1876 the first summary of the data on growth in stature into adult life is published by Topinard, in an article on "Étude sur la taille," in the *Revue d'Anthropologie*.[3] Topinard shows by his and other available though as yet not very satisfactory data, that growth in stature tends to keep on well into the adult period; and this conclusion is further sustained by the statistics on stature published in 1884 by the Anthropometric Committee of Great Britain.[4]

All this is relative to stature only. Parchappe's observations on the increase during adult life in the size of the head have evidently been forgotten.[5] Not until 1899 is there another contribution to this part of the question, this by an outstanding German worker, W. Pfitzner, who has examined and measured at Strassbourg, for age changes, 3,400 cadavers

[1] "On voit que la croissance de l'homme n'est pas entièrement terminée à 19 ans, pas même toujours à 25." (II, p. 15.)

[2] Gould, B. A., *Investigations in the Military and Anthropological Statistics of American Soldiers.* 8°, N. Y., 1869. Baxter, J. H., *Statistics, Medical and Anthropological, of the Provost-Marshall-General's Bureau.* 2 vols., 4°, Washington, 1875.

[3] V, pp. 34–83; "Influence of Age," pp. 37–43.

[4] Rep. 53rd meeting, B.A.A.S., London, 1884, pp. 290–291.

[5] Mentioned but not added to by Sauvage, H. E., "Sur l'état senile du crâne." *Bull. Soc. Anthrop.*, Paris, 1870, V, p. 578.

of (mainly) the Lower Alsatians.[1] This study extended for the first time to hair and eye color and, aside from stature and sitting height, to the principal measurements of the limbs, head, and face. The stature in the males showed a progressive slight increase on the average until after 30 (the 31–40 age period), the head increased until about 35, the face until about 45 years of age. Of the indices, the cephalic index was practically stable, while the breadth-height index of the head decisively diminished, the morphological face index decisively increased throughout adult life.

Before Pfitzner's work appeared, I myself commenced anthropometric researches on the American Indians and the subject of age from the start received due attention. The data regrettably could not be published until recently and even then not completely.[2] Meanwhile, however, from 1910 on, I carried out another piece of research with due attention to age, namely that on the old-American Whites, and this was published in 1925;[3] and this was supplemented since 1924 by studies on the mostly aged members of the National Academy of Sciences, which gave further valuable information on the role of the age factor in human dimensions. These latest data have not yet been published.

Finally, in 1935, Dr. Jarcho, of the Moscow University, reported[4] on "Age Changes in the Racial Features of the Adult," the results of measurements of considerable numbers of Kirghiz, Uzbeks, Armenians, and Russians, all males. The data related to stature, diameters of the head, face, nose, and ears, the thickness of the lips and the width of the mouth. Age changes were patent in all the groups. They consisted of perceptibly advancing growth in the various proportions to 30, 40 and even beyond 40 years of age, with senile diminution thereafter in stature and some of the main dimensions.

[1] "Der Einfluss des Lebensalters auf die anthropologischen Charactere," *Z. Morph. und Anthrop.*, 1899, I, pp. 325–377.

[2] Hrdlička, A., "The Pueblos, with Comparative Data on the Bulk of the Tribes of the Southwest and Northern Mexico." *Am. J. Phys. Anthrop.*, XX, pp. 235–460.

[3] Hrdlička, A., *The Old Americans.* Baltimore, 1925. A scientific detailed study of the fathers of America and their children.

[4] Jarcho, A., "Die Altersveränderungen der Rassenmerkmale bei den Erwachsenen." *Anthrop. Anz.*, 1935, XII, Hft. 2, pp. 173–179.

Details of Observations. Stature*

Quetelet (1836).[1]—Measured, at Brussells, three series of men of that city, of 300 individuals each, at the ages of 19, 25, and 30. The results were as follows:

Stature and Age in Men of Brussells

Age	19 Years	25 Years	30 Years
1st 100 of Each Series	166.3	168.2	168.3
2nd 100 of Each Series	166.9	167.3	168.7
3rd 100 of Each Series	166.2	166.9	168.2
All	166.5	167.5	168.4

The results show throughout that growth in body height, on the average, was not absolutely concluded by even 25, but kept on augmenting slightly to at least 30. There were indications of considerable individual variations in this respect.

This same author, in 1870, in his *Anthropometrie*[2] gives the following values for stature in Belgian men and women, without stating the numbers measured:

Stature and Age in Belgians

Age	20 Years	25 Years	30 Years	40 Years
Males	166.9	168.2	168.6	168.6
Females	157.4	157.8	158.0	158.0

A slight gradual stature increase, in the averages, up to at least 30, is seen again, and that in both sexes, though the progress in the females is rather insignificant.

Gould, Baxter (1869–1875).—An important addition to the subject is made, after the American Civil War, through the publications by Gould and then Baxter of the data on the stature of the soldiers of the northern armies.[3]

* Values expressed in cm., except where stated.

[1] Quetelet, A., *Sur l'homme et le développement de ses facultés, un essai de physique sociale.* 16 mo., Bruxelles, 1836, II, p. 15; see also p. 19.

[2] Quetelet, A., 8°, Bruxelles, table, p. 418.

[3] Gould, B. A., *Investigations in the Military and Anthropological Statistics of American Soldiers.* 8°, N. Y., 1869. Baxter, J. H., *Statistics, Medical and Anthropological, of the Provost-Marshall-General's Bureau.* 2 vols., 4to, Washington, 1875.

Gould, on p. 106 of his work, gives the statures by regions of enlistment, and by single years of age from 17 to 30, 31–34, and 35 and over, of 1,104,841 men. The data show:

1. That the rate of growth undergoes a sudden diminution at about the age of twenty years, the increase of stature continuing nevertheless uninterruptedly until about the age of twenty-four.

2. That for a year or two after this latter epoch the height remains nearly stationary, if indeed it does not diminish, after which a slight increase again manifests itself, and continues until the full stature is attained.

3. That the normal epoch of maximum stature must generally be placed, at least for American States,[1] as late as thirty years, but that it varies for different classes of men.

Gould tested the evidence in various ways and found nothing that would negate the above conclusions. Confining himself to the first six nativities of the schedule, "which include all the native Americans (United States), excepting less than 21,000 who were born west of the Mississippi River, and comprise more than eight-elevenths of all the white soldiers whose descriptive musters we possess; and if for these we compare the height at twenty-six years, last birthday (which represents the mean stature at 26.486 years of age), with the full stature subsequently attained, we find the excess of the later to be":[2]

	[illegible] Men	Excess of Full Stature
[illegible]	[illegible]	0.175 inches
[illegible]	[illegible]	0.134
[illegible]	[illegible]	0.229
[illegible]	[illegible]	0.250
[illegible]	[illegible]	0.163
[illegible]	[illegible]	0.193
	[illegible]12,411	0.148

[1] [illegible] Slave States, excluding Kentucky [illegible] twenty-nine and the number of [illegible]

[2] [illegible] Military and Anthropological Statistics of [illegible]

Arranging in a similar manner the annual variations of mean stature for the men enlisted in the several States, he obtained analogous results. The values from those nine States for the soldiers of which the maximum stature occurred after the age of thirty, are here presented:

AGE AND STATURE IN CIVIL WAR SOLDIERS (GOULD)[1]

State	22–23 Years	23–24 Years	24–25 Years	25–26 Years	26–28 Years	28 Years to Maximum
New Hampshire . . .	+0.194	−0.078	−0.006	+0.163	−0.014	+0.366 inches
Massachusetts . .	+0.042	+0.022	+0 038	−0.109	+0.006	+0.228
New York	+0.066	+0.012	−0.059	+0.132	−0.034	+0.055
New Jersey.	+0.139	−0.038	−0.034	−0.155	+0.126	+0.205
Pennsylvania.	+0.062	+0.037	+0.085	+0 058	−0.064	+0.135
Kentucky.	+0.099	+0.200	−0.377	+0.369	−0.005	+0.033
Ohio	+0.042	−0.014	+0.049	+0.014	+0.003	+0.100
Indiana.	+0.004	−0.079	+0.128	−0.041	+0 032	+0.105
Illinois	+0 000	+0.045	−0.054	+0.039	−0.028	+0·056

Topinard (1876).—Baxter's data conform in all essentials to those presented by Gould and need not be given apart, and both are made use of extensively soon after by Paul Topinard, in his "Study of Stature," in the *Revue Anthropologique of Paris*.[2]

Topinard mentions also two contributory studies on age and stature made in France. One of these was by Tenon,[3] which resulted in the recognition that "to obtain the true stature of a human group or race it is necessary to exclude subjects below 25 years and those above 50."[4]

The second report was that of Lélut,[5] on French "détenus" (persons arrested). Measurements of five age series of 400 men each gave the following results:

[1] Ibid., p. 111.
[2] "Étude sur la taille." *Rev. anthrop.*, 1876, V. pp. 34–83.
[3] "Notes relatives à la stature et au poids de l'homme." *Anales d'hygiène*, X
[4] Topinard, *Rev. Anthrop.*, V, p. 38. See also his *Éléments d'anthropologie générale*, 1885.
[5] *Sur la taille moyenne de l'homme en France.* Paris, 1841.

Age and Stature in French Criminals

Age	16.5–17.5 Years	Appr[illegible] [illegible] Years	25 Years	30–50 Years	50 Years or over
Subjects	400	400	400	400	400
Mean Stature	156.7	1[illegible]4.7	164.7	165.7	165.5

The maximum stature, it is seen, has been reached only after thirty.

Other authors mentioned by Topinard in this connection, but without bibliographic references, are Dunant and (John) Beddoe.

Dunant showed that the soldiers at Geneva who entered the service at 20 with a mean stature of 167.4 cm., fifteen years later have reached the mean height of 168.8 cm.; and for Beddoe the full stature in the British Isles was not attained until 30–33.[1]

Topinard concludes (pp. 42–3): "On the whole it is possible to make the following deductions: 1. Man's stature augments regularly up to 20, 25, 30 years or even over, according to individuals, so that to obtain a true full stature of a human group it would be necessary to include only those subjects who have finished the 35th year of their life; to be strict one should restrict the study to those between 35 and 45 years; in general, however, the end of growth occurs between 25 and 30." Racial differences remain uncertain.

Topinard shows additionally, from the data on the American soldiers and from a contribution by Sutherland,[2] that similar conditions regarding increase in stature after adult life is reached, as in the Whites, prevail also in the Negro, in the American Indian, and in the Eskimo.

Gould's statistics showed that full stature, on the average, was not attained until after 30 in both the American Negro and the Indian: data by Nondières[3] on 6,824 Annamites

[1] Topinard, R[illegible] V, p. 42.

[2] [illegible] d'E[illegible] de Kinookseok, Hogarth Sound, Cumberland Strait." *J. [illegible]*, 185[illegible], IV; Topinard, *op. c.*, p. 42.

[3] Topinard, *L[illegible]* [illegible] p. 431.

"leave the certainty that the end of development is not reached from 21 to 25 years, but lies beyond that." And the data of Trengrüber on 318 Kabyls of Algeria [1] indicate that the culmination of stature growth is realized well after 30.

The main details on other racial groups than Whites follow:

STATURE AND AGE

39,614 Negroes and Mixed (Gould)

Age	21–25 Years	26–30 Years	30–34 Years	35 or above
Mean Stature	167.0	170.5	170.6	170.4

498 Iroquois [2] (Gould)

	21–23 Years	24–26 Years	27–30 Years	31 or above
Mean Stature	171.6	172.6	173.5	174.2

29 Eskimo (Sutherland)

	16–20 Years	21–25 Years	26–30 Years	30 or above
Subjects	(10)	(4)	(6)	(9)
Mean Stature	155.5	158.0	159.1	158.4

However unsatisfactory these groups may be, the tendency toward slight progressive increase in stature after 20 and to or into the fourth decade, is seen in all, especially in the Iroquois.

England, 1884.—Relevant statistics on the population (in general) of Great Britain, published in the Final Report of the *Anthropometric Committee* in 1884 [3] show the following conditions:

AVERAGE STATURE

Age	20–24 Years	25–29 Years	30–40 Years	40–60 Years	60–70 Years
Subjects	(3,304)	(1,576)	(1,886)	(1,346)	(44)
Males (8,156)	171.7	172.2	172.7	172.6	171.2

[1] Ibid., p. 433.

[2] Good many doubtless with more or less of white blood (A.H.).

[3] Rep. 53*rd* Meeting B.A.A.S., London, 1884, pp. 290–291. No detailed data for females.

There is visible again the same tendency—the stature increases slightly up and into the fourth decade of life.

Pfitzner, 1899.—The next important contribution to the subject is that of the German anatomist, W. Pfitzner.[1] This noted worker attempted for the first time a comprehensive study of the effects of age on various physical characters during the adult life. His material consisted of 3,400 bodies of both sexes from the hospitals of Strassbourg, belonging mostly to the Lower Alsatians; and his studies were directed not only to stature but also to the main dimensions of the head and face, and to the length of the limbs.

Notwithstanding the disadvantages of measurements on dead bodies, Pfitzner's data present some valuable facts. So far as the changes in adult stature are concerned, before senile changes set in, his evidence is as follows:

STATURE AND AGE IN ALSATIANS

Age	20–25 Years	25–30 Years	31–40 Years	41–50 Years
Subjects (Males)	(39)	(52)	(98)	(133)
Mean Stature	166.9	167.0	167.5	166.2
Subjects (Females) . .	37	39	(75)	(92)
Mean Stature . .	157.5	156.5	156.7	155.5

The data indicate a slight gradual augmentation in body height in the males up to and into the fourth decade, with diminution thereafter; in the females the changes are irregular and once more rather insignificant.

Hrdlička, 1925, 1935.—The next contributions to the subject are those of my own studies on the old-American Whites, and on the American Indians. The latter began as early as 1898, to be published in the main only in 1935; the former were started in 1910 and published in 1925.[2] In both it became possible for the first time to make fairly extensive observations on age changes in the living populations at

[1] "Der Einfluss des Lebensalters auf die anthropologischen Charactere." *Z. Morphol. und Anthrop.*, 1899, I, pp. 325–377.

[2] Hrdlička, A., *The Old Americans*, 8°, Baltimore, 1925, 438 pp. "The Pueblos, with Comparative Data on the Bulk of the Tribes of the Southwest and Northern Mexico." *Am. J. Phys. Anthrop.*, 1935, XX, pp. 235–460.

large. The measurements included stature, height sitting, arm-span, and the principal diameters of the head, face, nose, mouth, ears, chest, hands and feet. The data on stature gave the following indications:

Age and Stature in Adult White Old-Americans[1]

Age	20–29 Years	30–39 Years	40–49 Years	50–59 Years
Males				
Subjects (235)	(91)	(63)	(47)	(34)
Mean Stature	174.1	175.0	174.5	174.0
Females				
Subjects (206)	(72)	(71)	(36)	(27)
Mean Stature	162.6[2]	162.0	162.4	159.2

Age and Stature in Adult Pueblo Indians

Age	Below 28 Years	28–50 Years	Over 50 Years
Males			
Subjects (263)	(49)	(164)	(50)
Mean Stature	163.7	163.9[3]	163.4
Females			
Subjects (107)	(24)	(70)	(13)
Mean Stature	152.1	152.1	150.3

Age and Stature in Other Adult Indians of the Southwest and Northern Mexico

Age	Below 28 Years	28–50 Years	Over 50 Years
Males			
Subjects (1,035)	(227)	(630)	(178)
Mean Stature	167.1	167.9	165.3
Females			
Subjects (425)	(81)	(292)	(52)
Mean Stature	155.0	155.1	154.1

The series are not as ample or uniform as would be desirable, but they all show the same trend, and this agrees with that of previous observations. The stature, in the males, increases perceptibly, in Whites and Indians alike, into about the fourth decade, after which it begins to diminish. In the females the increase after 30 is absent or insignificant.

[1] Laboratory series, subjects from general population.
[2] Younger generation tends to higher stature.
[3] Possibly affected somewhat by an excess of individuals over 40.

Bean, 1931.—Meanwhile, in 1931, Bean, in his article on the "Stature in Old Virginians,"[1] gave (p. 416) without discussion a table of data on both sexes arranged by age and extending from 7 years to 70. The more relevant part of his table is here reproduced:

Age and Stature in Adult Old Virginians

Age	21–25 Years	26–30 Years	31–40 Years	41–50 Years	51–60 Years
Males					
Subjects	504	493	188	(92)	(66)
Mean Stature	173.3	173.5	172.8	173.3	172.6
Females					
Subjects	112	145	(167)	(96)	(54)
Mean Stature	162.4	161.3	163.3	161.0	161.4

The results here are probably obscured by the fact already alluded to, the tendency namely of the younger generation toward a higher stature than that of the preceding one. This would raise the average in the youngest group and obscure the differences between them and the next. Regrettably it is impracticable to keep on measuring periodically, over perhaps 25 years, the same adults.

Jarcho, 1935.—In 1935, finally, there are published also the observations on age changes in the adult by Jarcho, on four of the ethnic groups of the Sovient republics.[2] The data, limited to males, extend to 18 measurements, besides visual observations. The next table gives the essentials on stature.

Age and Stature in Adult Male Russians, Kirghiz, Uzbeks, Armenians

Age	20–25 Years	26–39 Years	40 Years and over
Russians (807)	1[illegible]6.2	165.4	166.1
Kirghiz (772)	1[illegible]3.6	164.0	163.7
Uzbeks (672)	1[illegible]4.0	165.0	163.7
Armenians (602)	1[illegible]3.7	163.6	162.4

[1] Bean, R. B., *Amer. J. Phys. Anthrop.*, 1931, XV, pp. 355–419; with extensive bibliography.

[2] Jarcho, A., Die Altersveränderungen der Rassenmerkmale bei den Erwachsenen. *Anthrop. Anz.*, 1935, XII, pp. 173–9.

Except in the case of the Armenians, where probably some disturbing factor has entered the case, the data follow much the same course as that shown by all previous observations—the stature increases slightly up to, and probably more or less into, the fourth decade of life, to gradually begin to diminish soon after.

Summary and Discussion.[1]—The observations on age changes in stature during the earlier decades of adult life, extend now to the following ethnic groups:

Whites—the French, Belgians, English, Alsatians, Russians, Armenians, Old-Americans;

Yellow-Brown (and mixed)—Kirghiz, Uzbeks, Eskimo (a small group), American Indians;

Blacks—American Negroes and Mulattoes.

The data on males are much richer than those on the females, nevertheless there is enough of the latter for the appreciation of conditions in that sex.

Notwithstanding their various deficiencies, the available data are seen to tend in the same direction. They indicate that, on the average, growth in stature, more especially in the males, is not fully concluded when the age of 24, the ordinarily accepted age of maturity, is reached, or even when all the ephiphyses of the skeleton are joined to their bones (before 30); but that it proceeds slightly, through what can only be interstitial accretions, well into the 4th decade.

There doubtless exists, however, in this as in all other organic phenomena, much individual and probably even some group variation, but the mean tendencies are clear enough and evidently universal.

The Body Stem and Limbs

The only data on the proportions of the trunk and limbs at different ages during adult life, are those of Pfitzner and

[1] There are still some other more or less relevant data on changes in body height during adult life, in the rich literature on stature. They show in general similar conditions, except where some disturbing factors have evidently interfered. The following may be mentioned more especially: Roberts, Chas., *Manual of Anthropometry*, 8°, London, 1878; and Davenport, Ch. B., and Love, A. G., *Army Anthropology*, 8°, Washington, 1921.

my own. But these data are not comparable, for Pfitzner, measuring cadavers, was obliged to secure his determinations in a somewhat different way from that in which they are taken on the living.

Pfitzner, 1899.—As to the *stem height* (perineum-vertex), Pfitzner gives regrettably only the absolute proportions without their relation to stature. His figures show merely, therefore, that absolutely (barring what may be an incidental maximum between 20 and 25) the stem length augments slightly to between 31 and 40 (*o.c.*, p. 361).

Hrdlička, 1925, 1935.—In my *Old Americans*, p. 116, are given the ratios of stem length to stature for groups of 25 of the youngest and again the oldest of the subjects of both sexes, which show interesting conditions but do not bear on our present problem.

The Pueblo monograph contains some relevant data (*o.c.*, p. 279). They are given here slightly rearranged:

AGE AND HEIGHT SITTING IN THE ADULT PUEBLO INDIANS

Age	Below 28 Years	28–50 Years	Above 50 Years[1]
Males (183)			
Subjects	(37)	(116)	(30)
Mean Stem-Stature per cent ratio	*52.9*	*52.5*	*51.9*
Females (86)			
Subjects	(15)	(60)	(11)
Mean Stem-Stature per cent ratio	*52.0*	*53.2*	*52.3*

The data suggest that in the males there is no significant change in the relative proportions of the trunk and limbs until senility begins to set in, after which the relative height of the trunk decreases. This would imply that whatever changes in stature take place from below 28 to the beginnings of senile changes, they affect about equally the limbs and the stem. In the females conditions appear slightly different—the stem during the progressive period of the adult life increases slightly more than the lower limbs, to decrease at a greater rate after the initiation of the regressive changes.

[1] No old or decrepit included.

To the above may be added some as yet unpublished records on other Indians of the Southwest and of northern Mexico.

AGE AND HEIGHT SITTING; STEM-STATURE RATIO IN ADULT INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO OTHER THAN PUEBLOS

Age	Below 28 Years	28–50 Years	Above 50 Years[1]
Males (582)			
Subjects	(160)	(332)	(90)
Mean Stem-Stature per cent ratio	*52.8*	*52.5*	*51.5*
Females (284)			
Subjects	(57)	(199)	(28)
Mean Stem-Stature per cent ratio	*52.9*	*53.*	*52.2*

The conditions shown by the above table are practically identical with those of the Pueblos, which strengthens materially the tentative deductions made with the latter.

A somewhat noteworthy fact, apparent in both the Indian series, is the very slightly lower value of the ratio in the males, at 28–50, as compared with that below 28. There is one possible explanation, which is that of preponderance in each of the 28–50 male series of individuals above 40 or 45 years of age and hence showing already some of the effects of regressive changes. The subject needs further elucidation.

The Upper Limbs

Pfitzner, 1899, in his series of Alsatian bodies, studied also the effects of age on the adult arm length (acromion—tip of medius, right limb). Regrettably he gives again only the absolute values, not their relation to stature. In the males of his material, disregarding some irregularities, the arm length is seen to augment until the sixth decade; in the women from 20–25 on the changes are so small and irregular as to be insignificant.

Hrdlička, 1925, 1935.—In my own case the measurements were those of the arm span and were all made on the living.

[1] No old or decrepit.

In the old-American Whites, where the arm stretch was compared only in the youngest and oldest (up to 60) adults,[1] there were found marked differences in favor of the youngest, viz.:

OLD AMERICANS: ARM STRETCH AND AGE

Males

	Mean Age, Years	Stature	Breadth of Chest	Arm Stretch	Per Cent Ratio Arm Stretch Stature
25 Youngest...........	24	173.8	29.0	179.8	*103.5*
25 Oldest	59	174.6	29.9	175.8	*100.7*
		Females			
25 Youngest	24	163.0	26.2	162.3	*99.6*
25 Oldest.....	57	160.5	27.0	158.2	*98.6*

The breadth of chest, it is seen, was not responsible for the difference, which however is probably due not to any shortening of the upper limb, but to a diminution with age of the elasticity of the parts involved and the capacity to stretch.

The data on the Pueblos and other Indians are, it will be seen, more serviceable to the problem here dealt with, which is that of growth during a part of the adult age, though the grouping, made for other purposes, is not as detailed as would be desirable.

AGE AND ARM STRETCH IN ADULT PUEBLO INDIANS

	180 Males			*87 Females*		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Subjects..... ..	(37)	(114)	(29)	(15)	(60)	(12)
Mean Stature . ..	163.8	163.6	163.9	151.8	151.6	150.3
Mean Arm Stretch... . .	[illegible]	168.1	167.0	155.8	155.6	155.2
Per cent ratio of Arm Stretch to Stature	*102.9*	*102.8*	*101.9*	*102.6*	*102.6*	*103.3*

[1] *The Old Americans*, [illegible], 121–124.

AGE AND ARM STRETCH IN ADULT INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO OTHER THAN PUEBLOS

	447 Males			*234 Females*		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Subjects	(116)	(256)	(75)	(50)	(157)	(27)
Mean Stature	166.5	168.4	164.9	154.5	153.8	153.7
Mean Arm Stretch	171.6	172.6	169.2	155.0	156.4	156.5
Per cent ratio of Arm Stretch to Stature	*103.1*	*102.5*	*102.6*	*100.3*	*101.7*	*101.8*

In the Indians, barring the Pueblo males, there are some age differences in arm stretch, both absolutely and relatively; but there is visible no decided or regular tendency, particularly in the females.

THE HEAD

Perchappe (1836).—That a decrease in the volume of the head takes place during senility, was known more or less to various observers of the earlier parts of last century, among them Meckel (*Anatomie*), Tenon (*Mém. Instit.*, I), Soemmenig (C.H. fab., I), Béclard (*Anat. gén.*). That the dimensions of the head did not completely cease to enlarge when the adult life was reached, was first observed in 1836 by Parchappe.[1]

DIMENSIONS OF THE HEAD AND AGE IN THE ADULT FRENCH

	90 Males					*70 Females*				
Age	20–30 Years	30–40 Years	40–50 Years	50–60 Years	60 Years and over	20–30 Years	30–40 Years	40–50 Years	50–60 Years	60 Years and over
Subjects	(25)	(26)	(15)	(8)	(16)	(20)	(14)	(12)	(9)	(15)
Stature	168.1	168.5	168.4	172.5	166.6					
Head *diameters:*										
Length[2]	18.53	18.82	18.66	18.90	18.78	17.62	17.71	17.72	17.97	17.87
Breadth[3]	14.27	14.30	14.24	14.47	14.03	13.55	13.41	13.33	13.32	13.54
Arcs:										
Antero-post	34.82	34.99	34.69	35.10	34.66	34.25	34.18	33.29	33.74	33.33
Lateral	36.22	36.30	36.16	36.36	36.05	34.29	34.72	34.77	34.91	34.29
Anterior	30.20	30.77	31.09	32.25	32.10	29.0	29.37	30.43	30.05	30.02
Posterior	27.88	28.13	27.62	28.48	28.11	25.64	25.06	26.43	26.35	26.28

[1] Parchappes, *Recherches sur l'encéphale:* Vol. I, Du volume de la tête et de l'encéphale chez l'homme. Paris, 1836; chap. III, *Influence de l'âge sur la volume de la tête.*
[2] Maximum.
[3] Between points just above the auditory meati.

Parchappe found that the volume of the head in the French of his observations augmented sensibly to approximately the age of 50, after which there set in progressive sensible diminution. As the work is rare it will be of interest to reproduce here his tables.

There is no information as to just what social class or classes these measurements represent. The series are certainly inadequate, and the higher stature of the 50–60 year group of males disturbs. Nevertheless a slight general progression in the values of the different measurements, particularly in the males and up to at least the fourth decade, is noticeable. Parchappe had some impression that it was especially the fore part of the head that enlarged, and that this might be connected with the enlargement of the frontal sinuses; which is negatived by similar increases in the two sexes. His conclusion was (p. 23): "Augmentation in volume does not appear to cease at the time assigned as the end of growth in general, but seems, on the contrary, to continue gradually up to 60 years. This gradual increase is more marked in the males."

Pfitzner.—No further observations on head growth during adult life had materialized until 1899, when the subject was shown to have received a substantial test by W. Pfitzner.[1]

From his rich data (3,400 bodies of both sexes) Pfitzner reached the following deductions on the growth of the different head proportions:

Head Length

Males—maximum reached 31–40; only little further change.

Females—maximum reached 31–40; only little further change.

Head Breadth

Males—maximum reached 31–40, no significant change later.

Females—maximum reached 51–60, no significant change later.

[1] *Z. Morphol. und Anthrop.*, I.

Head Height

Males—maximum reached 25–40, slight diminution, but not progressive, later.

Females—maximum reached 25–40, slight diminution, but not progressive, later.

Head Circumference

Male—slight progressive increase throughout adult life.

Female—slight progressive increase to 80 years.

The data on which these conclusions were based are as follows:

AGE AND HEAD DIMENSIONS IN ADULT ALSATIANS

Age	15–20 Years	20–25 Years	25–30 Years	31–40 Years	41–50 Years	51–60 Years	61–70 Years	71–80 Years	81 Years and over
Males									
Subjects [1]	(72)	(60)	(86)	(178)	(232)	(295)	(239)	(170)	(42)
Head Length	18.42	18.55	18.56	18.69	18.60	18.69	18.66	18.73	18.75
Breadth	15.24	15.45	15.47	15.51	15.43	15.53	15.50	15.51	15.61
Height	12.09	12.31	12.20	12.22	12.13	12.19	12.17	12.14	12.16
Circumference	54.0	54.7	54.6	54.9	54.8	54.9	54.8	55.0	55.1
Females									
Subjects	(46)	(62)	(75)	(136)	(158)	(180)	(172)	(177)	(59)
Head Length	17.67	17.77	17.72	18.03	17.86	17.94	18.02	18.07	18.04
Breadth	14.70	14.68	14.76	14.84	14.83	14.90	14.85	14.88	14.89
Height	11.65	11.71	11.65	11.73	11.64	11.58	11.55	11.63	11.62
Circumference	52.0	52.4	52.5	52.9	52.7	52.8	53.0	53.0	52.8

The figures make plain that in all the head measurements except height there is a perceptible progressive enlargement during adult life with age. In height alone there are evidently no differences. Senile diminution in this group of subjects was evidently absent.

Regrettably Pfitzner gives only the absolute measurements without their relation to stature.

Hrdlička, 1925.—The next contribution to the subject are my studies on the Old Americans.[2] The results are here reproduced.

[1] There are slight differences in these numbers with the several head measurements, but they could have had no significant effect on the averages.

[2] *The Old Americans*, Baltimore, 1925, p. 150, table 98.

Age and the Three Head Diameters in Adult Old-American Whites[1]

Age	Males, Laboratory (247)			Males, Southern Engineers (347)			Females, Laboratory (210)		
	Length	Breadth	Height	Length	Breadth	Height	Length	Breadth	Height
20–29 Years	11.32	8.87	[illegible]	11.33	8.83	7.93	11.41	9.09	8.18
30–39	11.31	8.89	[illegible]	11.44	8.88	8.03	11.52	9.15	8.21
40–49	11.38	8.86	[illegible]				11.53	9.17	8.29
50–59	11.42	8.91	[illegible]				11.88	8.88	8.36
Above 59	11.31	8.79	[illegible]						

The conclusions reached were:

Head length—there is observable in both sexes a slight absolute as well as relative (vs. stature) augmentation of head length up to about the middle of the adult period.

Head breadth—a similar slight progressive increase as with length, absolutely as well as relatively to stature, is also observable with the breadth of the head, though in the males it is somewhat irregular, while in the females it appears to stop with the fifth decade. The older men and women of both the main series (Laboratory) show, as with length, slightly smaller dimensions than the rest of the adults.

Head height—in the females there is a slight but fairly regular absolute as well as relative increase in head height up to the sixth decade; but there is no appreciable growth in this proportion in the males.

The growth in the size of the head as a whole will best be seen from the next table, where the useful mean of the three head diameters, or cephalic module, is considered.

A gradual perceptible increase in head size throughout the earlier half of the adult period is seen quite plainly in both sexes in this group, and that both absolutely as well as relatively to stature.

Jarcho.—In 1935 Jarcho published his measurements on four large groups of males of the Soviet republics.[2] The data

[1] Groups of less than five subjects omitted.
[2] *Anthrop. Anz.*, XII, H. 2.

AGE AND THE MEAN HEAD DIAMETER IN ADULT OLD-AMERICAN WHITES[1]

Age	20–29 Years	30–39 Years	40–49 Years	50–59 Years	Above 59 Years
Males:					
Laboratory	(91) 16.35	(63) 16.40	(47) 16.43	(34) 16.43	(12) 16.27
Southern "Engineers" . .	(318) 16.34	(29) 16.39			
Laboratory:					
Stature	174.14	174.97	174.54	173.98	174.78
Per cent ratio of Cephalic Module to Stature.	*9.39*	*9.37*	*9.41*	*9.44*	*9.31*
Southern "Engineers":					
Stature.	174.33	173.54			
Per cent ratio of Cephalic Module to Stature.	*9.37*	*9.44*			
Females:					
Laboratory.	(72) 15.33	(71) 15.59	(36) 15.67	(27) 15.54	(3) (15.53)
Laboratory:					
Stature.	162.57	161.96	162.42	159.18	(166.07)
Per cent ratio of Cephalic Module to Stature.	*9.55*	*9.63*	*9.65*	*9.76*	*(9.35)*

AGE AND HEAD DIAMETERS IN FOUR GROUPS OF ADULT SOVIET PEOPLES[2]

Ages.	20–25 Years	26–39 Years	40 Years and above
Stature			
Russians.	168.2	168.4	166.1
Kirghiz.	163.6	164.0	163.7
Uzbeks.	164.0	165.0	163.7
Armenians.	163.8	163.6	162.4
Head Length			
Russians.	19.13	19.30	19.19
Kirghiz.	18.58	18.83	18.99
Uzbeks.	18.07	18.27	18.42
Armenians.	17.93	17.94	17.88
Head Breadth			
Russians.	15.16	15.16	15.08
Kirghiz.	15.95	16.01	16.08
Uzbeks.	15.72	15.71	15.70
Armenians	15.36	15.44	15.36
Head Height			
Russians.	13.00	13.14	13.05
Kirghiz.	12.85	12.99	12.90
Uzbeks.	13.08	13.02	13.09
Armenians.	—	—	—

[1] *The Old Americans*, table 128, p. 187.
[2] Abstracted by A. H.

extend to 807 Russians, 772 Kirghiz, 672 Uzbeks, and 600 Armenians. They are shown in table on page 867.

The four racial groups do not behave exactly alike, but there is a general resemblance. There is in all, it is seen, a plain increase up to at least 40 in head length, with less or none in breadth and less also in height. If the three dimensions in the three groups, where they are provided, be taken in their mean $\left(\frac{L + B + H}{3}\right)$, conditions are clearer:

AGE AND MEAN DIAMETER OF THE HEAD IN 3 GROUPS OF ADULT SOVIET PEOPLES

Age	20–25 Years	26–39 Years	40 Years and older
Russians	15.70	15.87	15.77
Kirghiz	15.79	15.94	15.99
Uzbeks	15.62	15.67	15.74

In two of the groups there is a slight progression in size of the head throughout the ages represented, in one up to at least the fortieth year. All the groups of this study, moreover, are those of non-intellectual workers.

Hrdlička, 1935.—My Indian data, published recently or still unpublished, relate partly to the Pueblos, partly to other Indians of the Southwest and northern Mexico.

AGE AND HEAD DIAMETERS IN ADULT PUEBLO INDIANS

Head	Length			Breadth			Height			Mean Diameter		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Males												
Subjects (174)	(34)	(111)	(29)	(34)	(111)	(29)	(34)	(111)	(29)	(34)	(111)	(29)
Means	18.3	18.3	18.3	15.07	14.95	15.11	13.71	13.70	13.88	15.63	15.65	15.75
Per cent of Stature	*11.[illegible]*	*11.[illegible]*	*11.[illegible]*	*9.1[illegible]*	*9.1[illegible]*	*9.25*	*8.36*	*8.37*	*8.49*	*9.55*	*9.51*	*9.64*
Females												
Subjects (85)	(21)	(53)	(11)	(21)	(53)	(11)	(21)	(53)	(11)	(21)	(53)	(11)
Means	17.9	17.7	17.7	14.42	14.53	14.80	13.27	13.33	13.60	15.05	15.22	15.39
Per cent of Stature	*11.7*	*11.[illegible]*	*11.7*	*[illegible]*	*[illegible]*	*(9.75)*	*8.72*	*8.82*	*8.96*	*9.90*	*10.01*	*10.13*

In the male Pueblos the length of the head remained unchanged; the breadth and height by the sixth decade had

perceptibly increased. In the females the head increased slowly with age to the sixth decade in all proportions.

These data may now be supplemented by the underneath unpublished records on other Indians of the Southwest.

AGE AND HEAD DIMENSIONS IN ADULT INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO OTHER THAN PUEBLOS

Head	Length			Breadth			Height			Mean Diameter		
Age....	Below 28 Years	28–50 Years	Above 50 Years[1]	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Males												
Subjects (929)..	(211)	(558)	(160)	(211)	(558)	(160)	(211)	(558)	(160)	(211)	(558)	(160)
Means.	18.50	18.66	18.69	14.92	15.09	14.76	13.38	13.46	13.48	15.60	15.74	15.64
Per cent of Stature......	*11.10*	*11.13*	*11.33*	*8.96*	*9.00*	*9.95*	*8.03*	*8.03*	*8.18*	*9.36*	*9.39*	*9.82*
Females												
Subjects (393)..	(76)	(267)	(50)	(76)	(267)	(50)	(76)	(267)	(50)	(76)	(267)	(50)
Means........	17.58	17.88	17.93	14.45	14.52	14.59	12.94	13.08	13.13	14.99	15.16	15.22
Per cent of Stature. ..	*11.20*	*11.62*	*11.65*	*9.21*	*9.40*	*9.48*	*8.25*	*8.49*	*8.53*	*9.55*	*9.84*	*9.89*

The above figures leave no doubt as to a gradual slight increase in the dimensions of the adult head among the Indians until approximately the sixth decade. In connection with the relative-to-stature data, it must be course be borne in mind that after about 45 the stature begins to decrease, which affects the relation.

Summary.—Since 1826 the subject of changes in head dimensions with age, during adult life, has received the attention of four workers. Their observations extended to four groups of Whites, namely the French, old-Americans, Russians and Armenians; and to several groups of Yellow-Browns or mixed, including the Uzbeks, Kirghiz, and a series of the tribes of the American Indians. The results are not entirely uniform and make it probable that there are some differences in the phenomena under consideration in contingents of even the same race. But the general tendency, particularly clear when the mean diameter instead of the separate dimensions of the head is considered, is plain enough. It shows that in the average the optimum size of the head is

[1] To approximately 60, with a few well-preserved older individuals.

not reached until the fourth, fifth or possibly even the sixth decade of life. The subject, however, is complex and will need much further study before definite detailed conclusions can be established.

As to what the adult augmentation in the size of the head may be due to is as yet problematical, but the indications are that their main cause is a progressive slight enlargement of the brain. There is no evidence that either the scalp or the bones of the vault thicken with age, while the enlargement of the head after 30 in the males and after 25 in the females, and that in breadth and even in height as well as in length, precludes the possibility of its being due, as was believed by Parchappe, to growth in the frontal sinuses. This seems to leave as the cause of the augmentation only a growth of the brain. Just why and how this should continue after adult life is reached, will be a point for future determination.

The Face

The study of the adult facial dimensions, more particularly that of the facial height, is seriously complicated by wear or loss of teeth and by absorption of the alveolar processes. Tooth wear is especially common and in later adult life pronounced in primitive peoples, while loss and absorption are frequent in the civilized Whites. Furthermore, the nasion, one of the two essential landmarks for the measurement of the height of the face proper, is difficult of precise location; though whatever bias may develop in regard to it is liable to remain constant with the same observer, so that individual comparisons such as are here dealt with would not be affected.

The face (less the forehead), must properly be viewed as only an adjunct or associate of the vault of the head. The only direct correlation between the two is that in breadth, and that is essentially of a simple mechanical nature. The functions and origin of the face and the vault differ radically, the face in the main being the product of the apparatus of mastication. Both the vault and the face, however, correlate in a measure directly with stature.

There enters still another factor into this subject, and that is that of habits. It is not certain with a series of white people that their masticatory habits or exertions have not changed in the course of time and affected the facial dimensions. Such a gradual change would certainly take place in a transit from less to more cultured condition of a people and that probably in a very few generations.

It is with these understandings that the subject of possible changes in the dimensions of the face with age, during the adult period, must be considered.

There are but three authors who paid special attention to such changes. They are Pfitzner, Jarcho, and the writer.

Pfitzner.[1]—Measurements on his large series of Alsatian (mainly) cadavers have shown this author that the facial height (to nasion), as well as the facial breadth, kept on enlarging perceptibly up to the period of 51–60, after which the changes were irregular and immaterial. His data follow:

AGE AND FACIAL DIMENSIONS IN ADULT ALSATIANS

Menton-Nasion Height

Age	20–25 Years	25–30 Years	31–40 Years	41–50 Years	51–60 Years	61–70 Years	71–80 Years	81 Years and over
Males								
Subjects	(60)	(78)	(150)	(205)	(258)	(204)	(153)	(39)
Means	12.13	12.06	12.35	12.41	12.54	12.48	12.57	12.83
Females								
Subjects	(57)	(70)	(119)	(145)	(162)	(153)	(171)	(58)
Means	11.08	10.94	11.18	11.11	11.21	11.20	11.30	11.25
Diameter Bizygomatic Maximum								
Males[2]								
Means	13.60	13.61	13.69	13.77	13.92	13.89	13.90	13.84
Females[2]								
Means	12.78	12.79	12.92	12.96	12.98	12.90	12.97	13.01

The data certainly bear out the author's conclusions—if no material cultural change has taken place in the population during the several generations represented by the subjects.

[1] Z. *Morphol. und Anthropol.*, I.

[2] Numbers of subjects with slight differences the same as with face height.

Hrdlička, 1925.—The work on the Old Americans [1] brought the first data on age changes during the adult stage in the living. The two principal measurements of the anatomical face gave the following values:

AGE AND FACIAL DIMENSIONS IN ADULT OLD-AMERICAN WHITES

	Males		Females	
Ages	25 Youngest Adults	25 Oldest [2] Adults	20 Youngest Adults	20 Oldest [2] Adults
Stature	173.8	174.6	164.5	159.3
Menton-nasion Height	11.60	12.02	11.05	11.09
Per cent of Stature	*6.68*	*6.88*	*6.72*	*6.96*
Diam. Bizygom. Max.	13.76	13.82	12.96	13.05
Per cent of Stature	*7.92*	*7.92*	*7.88*	*8.19*

OLD AMERICANS: FACIAL MEASUREMENTS AND INDICES, AND AGE

Facial Height to Nasion

	Males					Females				
Age	To 29 Years	30–39 Years	40–49 Years	50–59 Years	Above 59 Years [2]	To 29 Years	30–39 Years	40–49 Years	50–59 Years	Above 59 Years [2]
Subjects	(91)	(63)	(47)	(34)	(12)	(73)	(71)	(36)	(27)	(3)
Average	11.67	12.05	12.11	12.12	11.92	11.03	11.15	11.10	11.07	11.37
Per cent of Stature	*6.70*	*6.89*	*6.93*	*6.95*	*6.82*	*6.78*	*6.88*	*6.83*	*6.95*	*6.85*

Diameter Bizygomatic Maximum

Subjects	(91)	(63)	(47)	(34)	(12)	(73)	(71)	(36)	(27)	(3)
Average	13.80	13.92	13.89	13.97	13.82	12.93	13.0	13.06	12.99	13.40
Per cent of Stature	*7.92*	*7.96*	*7.91*	*8.03*	*7.91*	*7.95*	*8.03*	*8.04*	*8.16*	*8.07*

The conclusions that it seemed legitimate to draw from the above follow:

Taking the "youngest" and the "oldest" of the subjects, it is seen that in the absolute measurements, in the males, the face of the oldest is somewhat higher as well as slightly broader than that of the youngest. In the females similar

[1] *The Old Americans*, Baltimore, 1925, pp. 212–215.

[2] None aged or decrepit or materially affected by wear (negligible in Whites) or loss of teeth.

conditions prevail, the absolute values being slightly greater in the elderly. Relatively to stature, in the males, the oldest show a slightly greater relative height than the youngest, while the breadth ratios are identical. In the females, the ratio of the facial dimensions to stature is, in the case of every one of the measurements, quite perceptibly higher in the oldest than in the youngest of the group. In connection with the "oldest females," however, there is a probability that the stature had already suffered some senile reduction, which naturally would affect the ratio.

The records by decades throw a more intimate light on the conditions. These records make it plain that, notwithstanding some irregularity, the facial like the head proportions increase slightly with age in both sexes up to middle life, but that in the sixth decade, again as with the head, there occur for some reason smaller averages. These, when the intermediate groups are left out as in the first comparison, mask the changes that have taken place before.

In the Old Americans therefore, as in the Alsatians, the face appears to enlarge appreciably, during adult life, in both its height and breadth, and that up to the sixth decade.

Jarcho.—The measurements of this author apply to groups in which no substantial cultural change has taken place between the time of the older and younger subjects and where, therefore, the age effects may be expected to show more conclusively. The evidence is presented in the next table:

Age and Facial Dimensions in Adults of Four Groups of Soviet Population

	Menton-Nasion Height			Diam. Bizygomatic Max.		
Ages	20–25 Years	26–39 Years	40 Years and over	20–25 Years	26–39 Years	40 Years and over
Males						
Russians (807)	12.28	12.57	12.56	13.91	14.03	14.12
Kirghiz (772)	13.08	13.35	13.52	14.74	14.92	15.11
Uzbeks (672)	12.78	12.90	12.89	14.32	14.46	14.53
Armenians (600)	12.67	12.84	13.05	13.96	14.10	13.98

Though these data are not fully satisfactory as to the age subdivisions, they nevertheless are of no small importance. They conclusively corroborate both Pfitzner's and my observations. The face in both sexes, in all the groups thus far covered in this connection, tends to enlarge both in height and breadth with age, to fairly late in the adult period.

Hrdlička, 1935.—The latest contributions to this subject are the data given in my "Pueblo Indians, etc." [1] The main part of these records are here reproduced:

INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO

	Males			Females		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Menton-nasion Height						
Subjects	(211)	(606)	(160)	(77)	(269)	(50)
Average	11.71	11.86	11.76	11.01	11.17	11.16
Per cent of Stature	*6.99*	*7.06*	*7.00*	*7.57*	*7.24*	*7.24*
Diam. Bizygomatic Max.						
Subjects	(226)	(630)	(178)	(83)	(290)	(47)
Average	14.19	14.39	14.37	13.46	13.61	13.60
Per cent of Stature	*8.49*	*8.57*	*8.67*	*8.67*	*8.95*	*8.85*

PUEBLOS

	Males			Females		
Age	Below 28 years	28–50 years	Above 50 years	Below 28 years	28–50 years	Above 50 years
Menton-nasion Height						
Subjects	(51)	(342)	(52)	(24)	(68)	(15)
Average	11.73	11.59	11.65	11.03	11.18	11.05
Per cent of Stature	*7.17*	*7.05*	*7.14*	*7.26*	*7.37*	*7.27*
Diam. Bizygomatic Max.						
Subjects	(51)	(342)	(52)	(24)	(68)	(15)
Average	14.17	14.16	14.32	13.42	13.51	13.65
Per cent of Stature	*8.66*	*8.61*	*8.77*	*8.83*	*8.90*	*8.99*

The general tendency is plainly enough toward a slight progressive growth, both absolute as well as relatively to stature, in both the anatomical height and the greatest breadth

[1] *Am. J. Phys. Anthrop.*, XX, pp. 338–9.

of the face. It manifests itself in both sexes and proceeds evidently through most, if not all, the adult life before regressive changes become initiated.

Why the face, on the average, should proceed to enlarge during two or three decades after the mature stage is reached, can not as yet be definitely decided. There are, it seems, but two possible causes. The adult facial growth may correlate with similar growth in the vault of the skull; or it may be the result of the work performed by the apparatus of mastication. Both perhaps are involved. The matter will need special investigation on most suitable materials.

The Cephalic and Facial Indices

The main data on the behavior of these indices with age during adult life, are furnished by Pfitzner, Jarcho and the writer.

The Cephalic Index.—Pfitzner [1] in his study of the Alsatian dead, reached the conclusion that "the length-breadth index of the head throughout the entire extrauterine life is constant." His figures are here quoted:

AGE AND CEPHALIC INDEX IN LOWER ALSATIANS (POST MORTEM)
Males

Age, Years	Cephalic Index	Age, Years	Cephalic Index
0–1	83.5	25–30	83.4
1–2	83.5	31–40	83.0
2–4	83.6	41–50	83.0
4–10	83.9	51–60	83.1
10–15	82.5	61–70	83.1
15–20	82.7	71–80	82.8
20–25	83.3	81–100	83.5

What interests most for the present is that there was plainly no appreciable or regular change in the cephalic index of this group throughout the adult period.

In my *Old Americans* there is also no significant alteration:[2]

[1] Z. *Morphol. und Anthrop.*, I, p. 372.
[2] *O.c.*, pp. 168–9.

CEPHALIC INDEX AND AGE

	Males					Females				
Age	20–29 Years	30–39 Years	40–49 Years	50–59 Years	Over 59 Years	20–29 Years	30–39 Years	40–49 Years	50–59 Years	Over 59 Years
Laboratory	(91) 78.4	(63) 78.6	(47) 77.0	(34) 78.0	(12) 77.9	(72) 79.7	(71) 79.5	(36) 79.6	(27) 79.3	(3) 78.2
Southern "Engineers"	(318) 77.9	(29) 77.6								

Jarcho's data (1935)[1] do not agree with the previous. They show thus:

AGE AND CEPHALIC INDEX IN ADULT MALES OF FOUR GROUPS OF SOVIET POPULATIONS

Age	20–25 Years	26–39 Years	40 Years and above
Russians (807)[2]	79.3	78.6	78.5
Kirghiz (772)	85.9	85.1	84.9
Uzbeks (672)	87.0	86.0	85.3
Armenians (600)	85.8	86.2	85.9

Except in the Armenians, where the results are irregular, in all the three remaining groups the index diminishes steadily with age. The changes, especially in the Uzbeks and Russians, are so appreciable that they could hardly be attributed to accident.

The latest relevant data on the subject are those on my Pueblo and other American Indians.[3] They range as follows:

PUEBLO INDIANS. CEPHALIC INDEX IN RELATION TO AGE (UNDEFORMED HEADS)

	Males			Females		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Number of Subjects	(34)	(111)	(29)	(21)	(53)	(11)
Average	82.2	81.5	82.3	82.0	82.1	82.5

[1] *Anthrop. Anz.*, XII, table, p. 175.
[2] Of Tambov and Penza.
[3] *Am. J. Phys. Anthrop.*, XX, p. 310

Southwestern and North Mexican Indians, Exclusive of the Pueblos: Cephalic Index (Undeformed Heads)

Number of Subjects	(211)	(558)	(160)	(76)	(267)	(50)
Average	80.64	80.87	79.02	82.19	81.20	81.33

The indications from the above are not definite enough for any valid generalization. In the Pueblo males, and especially in the other-than-Pueblo Indian females, the youngest adults show a tendency toward a higher cephalic index than that of the older ages, or at least than that of the 28–50 year groups; but in the other series there is nothing regular. The data would seem therefore to partly support the evidence on the Alsatians and the Old Americans, partly that on the Russians, Kirghiz and Uzbeks. What appears certain is that Pfitzner's insistence on the "unchangeability" of the index can not be accepted. This is further supported by the growing evidence that in various human groups there is observable a perceptible change with time toward a relatively broader head. That there should be group differences in this respect must be expected.

The Morphological Face Index

The data on this ratio are given by the same authors as those on the cephalic index.

Pfitzner's observations on the Alsatian dead, from birth to oldest age, showed a progression in the numerical value of the facial index up to adult life. During the adult stage, as will be seen below, this progress is much slowed down (20–40), or even ceases (after 40). The maximum attained in high old age is I think incidental, due to alveolar absorption.

Age and the Morphological Facial Index in Adult Lower Alsatians (Post Mortem)

Age	20–25 Years	25–30 Years	31–40 Years	41–50 Years	51–60 Years	61–70 Years	71–80 Years	81 Years and over
Males	89.2	88.6	90.2	90.1	90.1	89.9	90.4	92.7
Females	86.7	85.5	86.5	85.7	86.4	86.8	87.1	86.5

The next data published are mine, on the Old Americans. Their gist follows:

[illegible] and the Morphological Facial Index in Adult Old-American Whites

	Males					Females				
	[illegible]	[illegible]	[illegible]	[illegible]	Over 59 Years	Up to 29 Years	30–39 Years	40–49 Years	50–59 Years	Over 59 Years
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]12	(73)	(71)	(36)	(27)	(3)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85.28	85.77	85.02	85.26	84.82

The evidence conforms in the main to that of Pfitzner. Up to approximately [illegible] in the males and 40 in the females the index rises, but after that tends toward diminution.

Jarcho's data of 1935 follow, and they too show partial agreement with, though also partial differences from, those of Pfitzner. In the [illegible] and the Armenians the facial index rises as far as the age groups reach, in the Uzbeks and [illegible] after the 26–39 year period.

[illegible] Adult Males of Four Soviet [illegible]

		[illegible] Years	40 Years and over
[illegible]	[illegible]	[illegible]	89.0
[illegible]	[illegible]	[illegible]	88.8
[illegible]	[illegible]	[illegible]	89.6
[illegible]	[illegible]	[illegible]	92.1

My data on the Pueblo [illegible] and those of Jarcho.[1] They show [illegible]

[illegible] Pueblo Indians

				Females		
	[illegible]	[illegible]	[illegible]	Up to 25 Years	26–50 Years	Above 50 Years
[illegible]	[illegible]	[illegible]	[illegible]	24	[illegible]	15
[illegible]	[illegible]	[illegible]	[illegible]	82.2	82.7	82.9

[1] [illegible] XX [illegible] 34–52.

Here, in the males, there is a perceptible decrease in the index with age or, as more correctly expressed, a gradual increase from the oldest to the youngest adults—the reverse of what was seen in the Pfitzner series of Whites and in Jarcho's Kirghiz and Armenians. The cause here is a gradual relative decrease, as we proceed from the old to the young, in the breadth of the face, brought about probably by a progressive advance in civilization. In the females conditions seem different, but the numbers of subjects are too small for any definite conclusions.

In the other Indians of the Southwest and northern Mexico matters are much the same as in the Pueblos, viz.:

Age and the Morphological Facial Index in Adult Indians of Northern Mexico and the Southwest, Other than Pueblos[1]

	Males			Females		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Subjects.........	(211)	(606)	(160)	(77)	(269)	(50)
Mean Index..... ..	82.5	82.4	81.8	81.8	82.1	82.1

It is plain that in the Indian males the facial index is not stable, nor increasing as the older generations are reached, but to a slight degree decreasing. The younger classes show progressively slightly less breadth of the face relative to its height. In the women conditions once more are indefinite.

Discussion.—The morphological facial index at different ages during adult life, does not tend to show equally in the two sexes, nor in all racial groups.

A word of caution is called for, however. As the age-series here considered are really series of persons of different generations, the changes apply to these generations and not to the life-course of the same individuals—a fact which must duly be borne in mind with all the evidence in these connections. Only in groups where physical alterations have not taken place in a group in the course of the years repre-

[1] Preliminary data.

sented by the series, due to changes in habits or other causes, may the changes be attributed to age proper. Such series are essentially those of the more primitive peoples.

An additional consideration is that the facial index depends on the facial height and the bizygomatic breadth, two largely independent variables, either of which may produce changes in the ratio. The same changes in the index could be due to diminishing facial height or increasing facial breadth, or vice versa, which renders it obligatory in all cases where this index or other similar ratios are considered, to pay due attention to the underlying absolute dimensions.

The Nose

The first data on the relation of the nasal dimensions and index to age that I have so far been able to locate, are my own observations on the Egyptians of the Kharga Oasis, published in 1912.[1] The data, partly rearranged, are given in the next table.

Kharga Oasis, Men: Nasal Measurements and Index in Relation to Age

Age	21 Youngest Adults, Mean Age 24.3[2]	42 Subjects, 35–45 Years	25 Oldest Adults, Mean Age 56.4[3]
Average Length	4.76	4.85	4.97
Average Breadth	3.60	3.72	3.90
Average Index	75.8	76.7	78.8
Per cent of Mean Nasal Length of Total Series (150)	97.7	99.2	102.1
Per cent of Mean Nasal Breadth of Total Series (150)	96.5	99.7	104.6

The comments on the above showing may here be quoted as then written: "They bear evidence to the fact that in general the nose grows both in length and breadth even after a fully adult life is reached, apparently even after 45 years of age; they show that the growth is perceptibly greater in the

[1] Hrdlička, A., "The Natives of the Kharga Oasis, Egypt." Smithson. Misc. Coll., Wash., 1912, LIX, No. 1, 118 pp. "Nose and Age," pp. 81–83.

[2] Only 2 subjects below 23; oldest 26.

[3] Highest age [illegible].

breadth than in the length; and as a result of these alterations the mean nasal index increases with age, advancing toward platyrrhiny. Judging from my experiences with the Indian, the augmentation in length ceases somewhere before the age limit of the series, and later on the dimension may diminish; but the breadth seems to increase slightly or retain its maximum proportions, unless affected by emaciation or pathological conditions, to the end of the life."

The next published records were those of my Old Americans.[1] The data are presented in two tables which deserve to be shown in full:

OLD AMERICANS: NASAL DIMENSIONS AND INDEX VS. AGE

	Males					Females				
	No.	Age, Years	Nose Height	Nose Breadth	Nasal Index	No.	Age, Years	Nose Height	Nose Breadth	Nasal Index
Youngest	(25)	24.2	5.23	3.50	*67.1*	(20)	23.0	4.90	3.15	*64.5*
General Average	(247)	42.5	5.35	3.61	*67.45*	(210)	41.0	4.95	3.25	*65.7*
Oldest........	(25)	59.5	5.52	3.78	*68.6*	(20)	57.2	5.07	3.38	*66.9*

RELATION OF NASAL DIMENSIONS TO HEIGHT OF FACE AND STATURE AT DIFFERENT AGES

	Males						Females					
			Per cent Ratio to Facial Height		Per mille Ratio to Stature				Per cent Ratio to Facial Height		Per mille Ratio to Stature	
	Height of Face Menton-nasion	Stature	Nasal Height	Nasal Breadth	Nasal Height	Nasal Breadth	Height of Face Menton-nasion	Stature	Nasal Height	Nasal Breadth	Nasal Height	Nasal Breadth
Youngest	11.60	173.78	*45.1*	*30.2*	*30.1*	*20.1*	11.05	164.52	*44.3*	*28.5*	*29.8*	*19.1*
Average	11.93	174.44	*44.9*	*30.2*	*30.7*	*20.7*	11.09	161.84	*44.6*	*29.3*	*30.6*	*20.1*
Oldest..... ...	12.02	174.63	*45.9*	*31.4*	*31.6*	*21.6*	11.09	159.27	*45.7*	*30.5*	*31.8*	*21.2*

The results parallel those obtained in the Egyptians. The nose, it is plain, grows with age in both length and breadth,

[1] *O.c.*, p. 253, Tables 181 and 182.

and the nasal index becomes higher with age, which means that the enlargement with age is slightly more in breadth than in the proximate (nasion-spine) length. Should we measure the dorsal or nasion-nasal point length the conditions would most likely be reversed.

In 1935 follow the data of Jarcho on four groups of the Soviet populations, and later the same year are published mine on the Indians. Jarcho's data follow:

Age and Nasal Dimensions in Adult Men of Four Groups of Soviet Populations

Age	20–25 Years	26–39 Years	40 Years and over
Nose Length			
Russians	5.40	5.57	5.67[1]
Armenians	5.43	5.56	5.68
Uzbeks	5.02	5.14	5.16
Kirghiz	5.10	5.14	5.31
Nose Breadth			
Russians	3.53	3.58	3.66
Armenians	3.50	3.57	3.64
Uzbeks	3.53	3.59	3.67
Kirghiz	3.61	3.72	3.85
Nasal Index			
Russians	64.7	65.2	65.1[1]
Armenians	65.3	64.4	64.5
Uzbeks	70.2	70.2	71.4
Kirghiz	71.8	72.95	72.95

These series suffer, from the point of view of the present study, from the lack of older categories of subjects; nevertheless they show in all the groups a progressive increase in both nasal height and breadth.

The latest contributions on age changes in the adult nose are my recently published data on the Pueblos and other Indians of the Southwest and northern Mexico. They are of considerable interest and are shown in table on page 883.

In both series and both sexes the measurements rise with age, and the index also rises, showing that while the nose enlarges with age in both dimensions it does so especially in breadth.

[1] Misplaced in the original.

Age and Nasal Dimensions in Adult Indians

Age...	Below 28 Years			All			Above 50 Years [1]		
Nose...	Length	Breadth	Index	Length	Breadth	Index	Length	Breadth	Index
Males									
Pueblos									
Subjects...	(43)	(43)	(43)	(377)	(377)	(377)	(33)	(33)	(33)
Means...	5.15	3.77	73.3	5.17	3.91	75.7	5.25	4.08	77.7
Other Indians of the Southwest and Northern Mexico									
Subjects...	(222)	(222)	(222)	(1139)	(1139)	(1139)	(178)	(178)	(178)
Means...	5.05	4.05	80.2	5.19	4.15	80.0	5.25	4.34	82.6
Females									
Pueblos									
Subjects...	(17)	(17)	(17)	(86)	(86)	(86)	(12)	(12)	(12)
Means...	4.76	3.51	73.7	4.85	3.62	74.7	5.09	3.87	76.0
Other Indians of the Southwest and Northern Mexico									
Subjects...	(84)	(84)	(84)	(476)	(476)	(476)	(54)	(54)	(54)
Means...	4.69	3.63	77.3	4.83	3.77	78.0	5.05	4.01	80.9

Résumé.—Available data on the relations with age, during adult life, of the nasal height, breadth, and index, extend now to eight ethnic groups, four of which are white (Egyptians, Old-Americans, Russians, Armenians), three yellow-brown (Kirghiz, Pueblos, other Indians), and one mixed (Uzbeks). In all these groups the evidence is substantially the same. There is a gradual increase in both the nasal dimensions throughout adult life, at least as far as the observations reach to approximately 65 years. But there is also throughout an increase with age of the nasal index, showing that the breadth of the nose increases proportionately slightly more than the length. How far into old age the process extends remains to be determined.

In this case it may safely be decided that the above are expressions of ontogenic conditions, unaffected or affected but slightly by the fact that the measurements extend to several generations.

[1] To 65 years.

The Ears

The first substantial contribution to the knowledge of ear changes with age during the adult period is that of Gustav Schwalbe. His data, given in the Virchow's Festschrift in 1891,[1] are as follows:

Age and the Ear in Adult Alsatians (Post Mortem)

Age.	20–29 Years	30–39 Years	40–49 Years	50–59 Years	60–69 Years	70–79 Years	80 Years and over
Males							
Subjects	(31)	(28)	(36)	(30)	(44)	(40)	(6)
Ear Length	6.03	6.37	6.34	6.59	6.74	7.01	(6.60)
Breadth ...	3.83	3.81	3.94	4.07	3.95	4.14	(3.91)
Index	*61.7*	*59.8*	*62.1*	*61.8*	*58.6*	*58.7*	*59.6*
Females							
Subjects...	(20)	(28)	(18)	(38)	(26)	(52)	(22)
Ear Length	5.86	5.91	5.84	6.08	6.29	6.53	6.60
Breadth	3.34	3.38	3.59	3.63	3.66	3.77	3.69
Index.....	*59.9*	*57.2*	*61.4*	*60.0*	*58.7*	*58.5*	*57.7*

Thus the ears are seen to grow slightly throughout adult life, until about 80 and possibly even after. Up to 50 the increase in breadth exceeds that in the length and the index rises; after 50 the length augments slightly more than the breadth and the index diminishes accordingly.

The next author who studied the adult ear in relation to age was Wilhelm.[2] He measured the ears partly in the living, partly on cadavers, in the sane, insane, and criminals. His 336 subjects were mainly French from Alsace and Lorraine. His data, though given with considerable detail, are regrettably not easily quotable for our purposes; but they agree, he states (p. 40), with those of Schwalbe—"the absolute length as well as breadth of the ear augment with age"; the ear index rises in general to the sixth decade, then diminishes due to a slightly greater proportional increase in the length.

In my own studies of the Egyptians, 1909 (published

[1] Schwalbe, G., "Beitrage zur Anthropologie des Ohres." Virchow's Festschrift, 1891, pp. 95–144.

[2] Wilhelm, E., "Matériaux pour servir a l'étude anthropologique du pavillon de l'oreille." *Rev. biol. du Nord etc.*, Lille, 1892, IV, 63 pp.

1912),[1] the left ear was measured in 105 adult males. The results are here abstracted:

AGE AND EAR DIMENSIONS IN ADULT EGYPTIANS

Age	Youngest Adults to 20 Years (17)	All (105)	Oldest Adults, 55–65 Years (17)
Ear Length[2]	6.05	6.3	6.65
Breadth	3.6	3.7	3.75
Index	*59.5*	*58.9*	*56.3*

There were not enough subjects to demonstrate the changes by decades of life. All the figures show therefore is the increase in ear dimensions with age, a proportionately greater eventual growth in length than in breadth and a consequent decrease in the ear index.

The next published records are those which I obtained on the Old Americans.[3]

AGE AND THE EAR IN ADULT OLD-AMERICANS

	Males					Females			
Age	24–29 Years	30–39 Years	40–49 Years	50–59 Years	Above 59 Years	22–29 Years	30–39 Years	40–49 Years	50–59 Years
Subjects	(91)	(63)	(47)	(34)	(12)	(73)	(71)	(36)	(27)
Ear Length	6.49	6.56	6.87	7.05	7.13	6.03	5.99[4]	6.23	6.40
Breadth	3.71	3.79	3.80	3.90	4.05	3.43	3.45	3.53	3.56
Index	*57.2*	*57.8*	*55.3*	*55.3*	*56.8*	*56.9*	*57.6*	*56.7*	*55.6*

The results are much the same as those of Schwalbe, Wilhelm, and in my Egyptians. The ears keep on growing slightly up to at least the sixth decade. Up to approximately 40 the increase in breadth exceeds that in length and the index rises; after that conditions become reversed, the length increases proportionately more than the breadth and the ear index diminishes.

[1] "The Natives of Kharga Oasis, Egypt." Smiths. Misc. Coll., 1912, LIX, p. 94.

[2] Measurements same as those of Schwalbe's a–b, c–d; index = Schwalbe's "physiognomic index."

[3] *O.c.*, 1925. Table 232, p. 297.

[4] A chance aggregation of low ears.

The year 1935 brings the measurements of Jarcho, which include those on the ears in four groups of males of the Soviet populations.[1] Regrettably the ears of the Russians proper were not measured.

AGE AND THE EAR IN ADULT MALES OF THREE GROUPS OF THE SOVIET PEOPLES

Age	20–25 Years	26–39 Years	40 Years and over
Ear Length			
Kirghiz	6.20	6.32	6.46
Uzbeks	6.20	6.27	6.51
Armenians	6.04	6.25	6.51
Ear Breadth			
Kirghiz	3.46	3.70	3.71
Uzbeks	3.52	3.53	3.63
Armenians	3.63	3.79	3.82
Ear Index			
Kirghiz	55.8	58.5	57.4
Uzbeks	56.8	56.3	55.8
Armenians	60.1	60.6	58.7

The above results conform fully to previous observations. The ears keep on growing appreciably to old age, but the length and breadth do not grow harmoniously. Up to about 40 the breadth augments a trace faster than the length and the ear index rises; after that the length grows a trace more than the breadth and the index diminishes.

There are regrettably no adequate age data on the ear, as yet, on the Indians and the Eskimo; but what there is presents no evident exceptions to what has appeared in other racial groups. Bean has commented briefly on this subject.[2]

Résumé.—Data on continued ear growth during adult life are now available from four authors: on the Alsatians (and Lorraines), on one of the groups of Egyptians, on the Old Americans, and on the Armenians, Kirghiz, and Uzbeks. They are exceptionally harmonious. They show definitely that the ear grows slowly to old age; that up to about 40 it increases, proportionately, slightly more in the breadth, after

[1] *Anthrop. Anz.*, 1935, XII, p. 175.

[2] Bean, R. B., "Some Characteristics of the External Ear of American Whites, American Indians, American Negroes, Alaskan Esquimos, and Filipinos." *Am. J. Anat.*, 1915, XVIII, pp. 201–219.

that slightly more in the length; and that as a result the ear index $\left(\frac{B \times 100}{L}\right)$ up to 40 rises gradually, after that diminishes.

The Mouth

Measurements of mouth width in the adult, in relation to age, were made by the writer on the Egyptians, Old Americans and Indians; and by Jarcho on three groups of the Soviet peoples. The data are here presented in the order of their publication.

Age and Mouth Width in Adult Male Kharga Oasis Egyptians [1]

	Narrowest Mouths (23 subjects)	Broadest Mouths (20 subjects)
Mean Age	35 yrs.	44 yrs.
Mean Width	5.0 cm.	5.9 cm.

The older adults at Kharga have in general broader mouths than the young adults.

Age and Mouth Width in Adult Old-Americans [2]

	Males			Females		
	In 25 Youngest	All (247)	In 25 Oldest	In 25 Youngest	All (210)	In 20 Oldest
Mouth	5.22	5.37	5.73	4.63	4.95	5.20
Stature	176.3	174.4	174.5	164.5	161.8	159.3
Mouth-Stature per mille ratio	*29.6*	*30.8*	*32.8*	*28.1*	*30.6*	*32.7*

The conclusions reached with this important group may best be quoted in full: "Taking the mouth width in the youngest and the oldest of the Old Americans, there appears in both sexes a rather marked difference in favor of age. Evidently the mouth, like the nose and other facial parts, grows with age, and the age factor, usually neglected, may account for a good many of the apparent group differences in the feature that have been recorded in anthropological literature. In the males the difference within the moderate age range of

[1] *The Natives of the Kharga Oasis*, p. 88.
[2] *The Old Americans*, pp. 267–270.

our series is near 9 per cent, in the females as much as 11 per cent, and that notwithstanding the fact that the stature, with which the size of the mouth stands in direct correlation, is higher in the young than in the old groups. In the young adults, especially in the females, the mouth is therefore both absolutely and relatively to stature smaller than it is later in life, showing that the mouth grows during adult life independently of stature."[1]

Jarcho's data agree fully, as far as they go, with the above:[2]

AGE AND MOUTH WIDTH IN ADULT MALES IN THREE GROUPS OF SOVIET POPULATIONS

Age	20–25 Years	26–39 Years	40 Years and over
Armenians (600)	5.29	5.48	5.65
Uzbeks (672)	4.95	5.15	5.32
Kirghiz (772)	5.02	5.10	5.36

The mouth widens progressively in all three groups, as far as the ages reach; and the differences between the youngest and the oldest series are remarkably similar, though their racial affiliation differs.

Hrdlička's records on Indians:[3]

AGE AND MOUTH WIDTH IN ADULT PUEBLO AND OTHER INDIANS

	Males			Females		
	Subjects	Mouth Width	Per mille of Stature	Subjects	Mouth Width	Per mille of Stature
Pueblos						
Below 28 yrs.	(37)	5.34	*32.6*	(17)	4.93	*32.5*
Above 50 yrs.	(30)	5.85	*35.7*	(12)	5.52	*36.8*
Other Indians of the Southwest and Northern Mexico						
Below 28 yrs.	(162)	5.64	*33.3*	(52)	5.19	*33.6*
Above 50 yrs.	(97)	6.07	*30.6*	(30)	5.69	*39.1*

[1] It is of course necessary in this connection to discount any possible senile diminution in stature.

[2] *Anthrop. Anz.*, 1935, p. 175.

[3] "The Pueblos, etc.," *Am. J. Phy. Anthrop.*, XX, 1935.

The figures need but little comment. The mouth widens with age, even in relation to stature, and this widening is not due to a relaxation, but to actual enlargement of the orifice.

Résumé.—Measurements of mouth width in adults, in relation to age, are available on seven ethnic groups. They show throughout that the mouth increases with age and that in both sexes. How far into old age this increase goes on is not demonstrable, the present data not reaching beyond the seventh decade.

The Chest

The only observations on the proportions of the adult chest in relation to age, are so far those of the writer, and they extend only to the Old Americans and the Indians. The reason is that generally in the past the only chest measurement taken was the circumference, which gave only the size of the thorax.

The measurements to be dealt with here are the chest breadth and depth at the level of the nipples in men and of the upper border of the fourth chondrosternal articulation in women.[1] The $\frac{D \times 100}{B}$ ratio gives the chest index. These measurements and indices are of decided value to anthropology. They show interesting progression in childhood, and, as will be seen from the data that follow, also in the adult. The records are given in the next tables.[2]

Age and Chest in Adult Old-American Whites

	Males				Females			
	Number	Breadth	Depth	Index	Number	Breadth	Depth	Index
Youngest	(25)	29 03	20.61	*70.99*	(25)	26.10	19.34	*74.10*
General Average	(247)	29.76	21.70	*72.93*	(210)	26.62	20.03	*75.30*
Oldest	(25)	29.92	23.03	*76.97*	(25)	26.82	20.96	*78.15*

[1] See Hrdlička, A., *Anthropometry*. Wistar Inst., Phila., 1920.

[2] For additional details see *The Old Americans*, 1925, pp. 306, 311; and *The Pueblos, etc.*, 1935, p. 411.

The above figures disclose plainly that "the chest increases in size with age after supposedly full growth has been reached, and also that it increases unevenly. It grows during adult life moderately in breadth, but more markedly in depth, particularly so in the males, thus reversing the conditions during childhood and adolescence. The chest in the young adults is flatter than in those after fifty, which is very clearly expressed by the chest index: and the chest of the females is relatively shallower than that of the males at all ages."

AGE AND THE CHEST IN ADULT PUEBLO INDIANS

Age	Below 28 Years		28–50 Years		Above 50 Years	
Males						
Subjects	(37)		(116)		(30)	
	Mean	Per cent of Stature	Mean	Per cent of Stature	Mean	Per cent of Stature
Chest Breadth	30.2	18.4	30.0	18.3	29.1	17.7
Depth	21.0	12.8	21.8	13.3	22.9	14.0
Index	*69.7*		*72.7*		*78.8*	
Females						
Subjects	(17)		(58)		(12)	
Chest Breadth	28.8	19.0	29.5	19.4	28.1	18.7
Depth	20.5	13.5	22.1	14.6	23.7	15.8
Index	*71.2*		*75.0*		*84.4*	

Notwithstanding the more or less inadequate numbers of subjects the results are definite.

In breadth, in the male Pueblos, there is evidently a slight progressive decrease, both absolutely and relatively to stature, from probably the latter part of the 28–50 period onward; in the females a similar decrease is manifest only after 50.

In the depth of the chest, however, there is in both sexes a marked both absolute as well as relative-to-stature increase throughout the ages represented by the subjects (to 65).

In consequence of the progressive excess of the depth of the thorax over its breadth, the chest index rises markedly throughout the adult period, within the limits of the material.

The following records show the conditions in the larger series of other Indians of the region:

Age and the Chest in Adult Indians of Northern Mexico and the Southwest Other than the Pueblos

Ages	Below 28 Years		28–50 Years		Over 50 Years	
Males						
Subjects	(153)		(332)		(89)	
	Mean	Per cent of Stature	Mean	Per cent of Stature	Mean	Per cent of Stature
Chest Breadth	29.5	17.7	30.1	18.3	29.6	17.9
Depth	22.1	13.2	23.0	13.7	23.4	14.2
Index	*74.8*		*76.0*		*79.0*	
Females						
Subjects	(58)		(199)		(29)	
Chest Breadth	27.6	17.8	28.4	19.5	27.9	18.2
Depth	20.5	13.2	21.8	14.1	22.6	14.7
Index	*74.3*		*79.5*		*80.9*	

These figures cover Indian tribes living under a variety of climatic and other conditions, in consequence of which the absolute figures differ more or less, from those of the Pueblos but the trend of changes with age is the same. Chest breadth increases to at least 40, then diminishes. Chest depth increases both absolutely and relatively throughout the adult period represented, and the chest index increases accordingly.

Summary.—Observations on age changes during adult life in the thorax are now available on the Old-American Whites, and on two groups of the American Indian.

The results on all three groups show a substantial agreement. The chest in the Indians keeps on increasing slightly

THE HAND AND AGE: THE PUEBLOS

	Males			Females		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Hand Length						
Number of Subjects	(37)	(116)	(30)	(17)	(58)	(12)
Average	18.11	18.02	18.09	17.01	17.26	17.39
Per cent of Stature	*11.03*	*11.00*	*11.01*	*11.22*	*11.38*	*11.57*
Hand Breadth						
Average	8.30	8.29	8.20	7.54	7.57	7.67
Per cent of Stature	*5.07*	*5.07*	*5.07*	*4.98*	*5.11*	*5.11*
Hand Index						
Average	*45.90*	*46.01*	*45.36*	*44.34*	*44.09*	*44.13*

THE HAND AND AGE: OTHER INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO

Hand Length						
Number of Subjects	(135)	(302)	(78)	(46)	(183)	(28)
Average	18.51	18.50	18.34	16.89	17.31	17.29
Per cent of Stature	*11.05*	*11.07*	*11.09*	*10.91*	*11.15*	*11.25*
Hand Breadth						
Average	8.44	8.54	8.47	7.52	7.75	7.75
Per cent of Stature	*5.04*	*5.08*	*5.12*	*4.86*	*5.01*	*5.04*
Hand Index						
Average	*45.63*	*45.95*	*46.21*	*44.53*	*44.89*	*44.82*

PUEBLOS: THE FOOT AND AGE [1]

	Males			Females		
Age	Below 28 Years	28–50 Years	Above 50 Years	Below 28 Years	28–50 Years	Above 50 Years
Foot Length						
Number of Subjects	(37)	(116)	(30)	(17)	(58)	(12)
Average	24.27	24.37	24.40	22.33	22.33	22.42
Per cent of Stature	*14.81*	*14.90*	*14.89*	*14.73*	*14.63*	*14.91*
Foot Breadth						
Average	9.40	9.48	9.61	8.86	9.04	9.00
Per cent of Stature	*5.74*	*5.79*	*5.86*	*5.84*	*5.95*	*6.02*
Foot Index						
Average	*38.75*	*38.87*	*39.40*	*39.67*	*40.64*	*40.37*

[1] *Op. c.*, p. 445.

INDIANS OF THE SOUTHWEST AND NORTHERN MEXICO: THE FOOT AND AGE

Foot Length						
Number of Subjects...	(135)	(302)	(78)	(46)	(183)	(28)
Average...	25.33	25.55	25.04	22.79	23.45	23.15
Per cent of Stature...	*15.13*	*15.22*	*15.14*	*14.72*	*15.16*	*15.06*
Foot Breadth						
Average...	10.05	10.15	10.28	8.78	9.12	9.23
Per cent of Stature...	*5.78*	*6.04*	*6.21*	*5.67*	*5.90*	*6.01*
Foot Index						
Average...	*30.70*	*30.70*	*41.05*	*38.53*	*38.02*	*39.90*

In the Pueblos, no change in the hand with age is observable within the ages and numbers to which the series are limited in the males, but in the females there is the same slight increase with age, in both hand length and breadth, as in the Whites. The index in both sexes changes but very immaterially. In the male Indians used for comparison with the Pueblos, though conditions are not as clear as desirable, the relative values of the two hand measurements show a slight sustained increase with age; while in the females of these tribes increase in hand dimensions is plainly observable up to at least middle age. The hand index, however, here too remains much the same at all ages.[1]

As to the foot, in the Whites the foot, like the hand, was found to grow slightly during adult life in both main dimensions, though a trace more in breadth than in length.

In the Pueblos and other Indians of the region conditions are essentially the same. The slight growth during the adult stage is more marked in the females than in the males, and more in the breadth than in the length. The increase, while small, is both absolute and relative to stature and is therefore a genetic reality. That it is plainer than it was in the Whites is due, I think, to the untrammelled condition of the Indian foot.[2]

General Remarks.—Every author who contributed to the study of age changes in the adult touches more or less on the need of due attention being paid to this factor. There are,

[1] *O.c.*, p. 430.
[2] Ibid., p. 444.

however, but a few notes on the subject in Topinard's *Anthropologie Générale*[1] and in Martin.[2] Moreover, that in the latter on the ear (p. 724), the enlargement of which with age is stated to be "brought about by a flattening of the curves of the concha and a diminution in the elasticity of the skin," is erroneous.

The most explicit statements on the matter are those of Quetelet and Jarcho. Quetelet (*Anthropométrie*, 1870, p. 45) says: "Age, without contradiction, is the modifying cause that acts most powerfully on the proportions of the body. . . . Under its active influence the body, outside of all the other conditions that can make it vary, presents from birth to the most advanced time of life an admirable spectacle which can not be studied with too much attention."

Jarcho (*Anthop. Anz.*, 1935, XII, p. 179): "All the facts here dealt with lead to the conclusion that in racial studies age-modification of the racial type must receive due attention. Not seldom where we think to find race mixtures there are present only age changes of the given racial type."

General Summary and Conclusions

There exists now sufficient evidence to show that the growth and development of the body as a whole and of many, if not all, its parts, is not fully accomplished by what is generally regarded as the reaching of maturity, but proceeds more or less into the adult stage.

Not all the parts advance at the same rate, nor equally as long; and there are considerable individual variations.

The majority of the dimensions or characters, headed by stature, progress perceptibly on the average until well into the fourth decade of life; others, including the skull and the face, increase slightly, in some groups at least, until the fifth or even the sixth decade; and still others, such as the dorsal length and breadth of the nose, the length of the ears, width of the mouth, depth of the chest, keep on augmenting generally throughout most, if not all, of the adult existence.

[1] Pp. 418–19, 1896.

[2] *Lehrbuch d. Anthrop.*, 2nd ed., I, pp. 565, 571; II, p. 724.

All these processes are doubtless affected by physiological factors, such as work and nourishment, as well as by pathological conditions.

From the anthropological point of view, these new recognitions are of basic importance. It is seen that thoroughly representative series can be those of subjects between 30 and 45 years of age only. It is further evident that age changes, both absolute and relative, in other words age changes in both measurements and indices, may obscure, or even exceed group or racial differences. This means that henceforth thorough attention, in all anthropometric procedures on the adult, must be paid to age, and that much of the anthropometric work on the adult of the past must be replaced by more selective and critical observations.

This furnishes a vast renewed field to Anthropology. It brings the appreciation that we are still largely in the infancy of the science of man, and that there lies. while laborious, a wonderful future before this branch of endeavor; the fruits of which, moreover, must eventually be not only of academic but also of medical and other practical importance.

U. S. National Museum.

PALISOT DE BEAUVOIS AS AN OVERLOOKED AMERICAN BOTANIST

E. D. MERRILL

ABSTRACT

Baron Palisot de Beauvois, 1752–1820, was peculiarly unfortunate in his botanical field work. He left France in 1786 to explore the region about the Gulf of Guinea, West Africa, expecting to return within four years. He did not return to France until after an adventurous twelve years in Africa, in Haiti, and in the United States. Within six months 250 of the party of 300 men who went to Owara on the Gulf of Guinea died of fever and Palisot de Beauvois became so ill that he was sent to Haiti on a slave ship to recuperate. His extensive African collections were burned when the English destroyed the trading station at Owara on the Gulf of Guinea in 1791; collections assembled in Haiti over a period of three years were burned by the insurgent slaves when Beauvois' house at Cap Haitien was destroyed in 1793. His extensive United States collections made between the years 1793 and 1798 from New York to Ohio south to Georgia were lost in a ship wreck near Halifax while in transit to France in 1798.

Palisot de Beauvois was captured by the Haitian insurgents but through the intervention of a mulatto was saved from execution and deported to the United States. He had made his first trip to Philadelphia in 1791 as a commissioner of the Haitian colonial government; he landed a second time in Philadelphia in 1793 utterly penniless as the American ship on which he was a passenger was intercepted by the British who seized all his belongings. In the meantime the French revolutionary government had placed his name on the list of *émigrés* and he could not return to France on pain of death. For a time he supported himself in Philadelphia by teaching French and music, being befriended by Dr. Caspar Wistar and by C. W. Peale; for a time he assisted in Peale's museum and prepared and published a descriptive catalogue of the museum.

He was elected to membership in the American Philosophical Society January 20, 1792, and resided in Philadelphia at four different intervals between 1791 and 1798. The only reason that he does not rank with his compatriot, Michaux, as one of the important early botanical explorers of North America was due to the tragic loss of his collections while in transit between Philadelphia and Paris; in fact in the twelve adventurous years that he spent away from France he lost, through no fault of his own, three great collections of natural history material that he had laboriously assembled in Africa, in Haiti, and in the eastern United States. Yet after his return to France he devoted the remaining twenty-two years of his life largely to the study of botany, preparing and publishing many short papers and several large and important works, one, remarkably well executed and so rare, that a complete copy of the two volume work has recently been quoted at a price of $900.00. His first technical papers were actually prepared in Philadelphia and were published by the American Philosophical Society. This organization has in its archives various original letters of Beauvois addressed to Caspar Wistar, Thomas Jefferson, and others.

SEVERAL years ago I acquired two broken sets of Palisot de Beauvois' *Flore d' Oware et Benin en Afrique*,[1] and when

[1] **Palisot de Beauvois, A. M. F. J.** *Flore d' Oware et Benin en Afrique*, 1: i–xxii, 1–100, *t. 1–60*, 1805–10?; 2: 1–95, *t. 61–120*, 1810?–21.

these were collated it was found that the two volumes lacked only a few pages of text and a few plates. These broken sets fortunately included 6 of the very rare original fascicle covers bearing the dates of issue of the several parts. Complete sets of this publication are so rare that in 1928 Quaritch listed a copy of the edition with colored plates priced at £180. In describing it he wrote: "This is the only complete copy I have had and the only one that has appeared at auction for at least twenty-five years." Two editions were issued, one with colored, the other with black and white plates. Pritzel gives the title-page dates, Vol. 1, 1804, and Vol. 2, 1807, stating "Rarum idque pulcherrimum opus prodiit 20 fasciculis usque ad annum 1818 vel 1821." Each fascicle consists of six plates and a certain amount of text. It has long been known that the title-page dates were incorrect for the complete volumes, and that the dates on some of the fascicle covers were probably wrong. Data appertaining to the dates of issue of the several parts, prepared by Dr. J. H. Barnhart, are appended to this paper.

What intrigued me, however, was neither the rarity of the publication, nor its general content, but a statement by A. Jussieu, on page viii of Volume one, in which he refers to Palisot de Beauvois' residence in Philadelphia. Except as the author of various well known genera and species of Gramineae, the name Palisot de Beauvois seldom appears in American botanical literature. Certain species, however, *e.g.* *Anemone minima* DC. Syst., 1: 206, 1818, were described from specimens collected by him in the eastern United States. Consulting Harshberger's volume on Philadelphia botanists,[1] I could find no reference to Palisot de Beauvois. It then occurred to me that an inquiry into the matter might determine the cause of Harshberger's omission and, more significantly, the reason why Palisot de Beauvois has remained practically unknown as an early collector of American plants.

[1] **Harshberger, J. W.** *The Botanists of Philadelphia and their Work*, i–xii, 1–457, *illus.*, 1899.

A number of sketches of Palisot de Beauvois' life and work have been published,[1] from which it is possible to obtain much information regarding his rather remarkable career. Fortunately, data from the archives of the American Philosophical Society throw some light on his botanical activities in this country. The obscurity of his name in the botanical literature of the West Indies and of the United States is due to the tragic loss of his Haitian and most of his United States collections.

A. M. F. J. Palisot, Baron de Beauvois, was born at Arras, France, July 27, 1752 (not October 28, 1755, as stated by some authors). He was educated at Harcourt College in Paris, and was admitted to the bar in 1772. After the death of his father and the subsequent death of his older brother, he inherited the patriarchal estates and also the position of receiver of the domains and forests of northern France. In

[1] **Jussieu, A. L. de.** Extrait de la Dècade philosophique, No. 10, IIe trimestre an XII. [Flore d'Oware et de Benin] in Palisot de Beauvois *Flore d' Oware et Benin en Afrique,* 1: viii–xi, 1805. Reprinted from *Décade philosophique,* 10 nivôse, An xii, 1–8, 1804.

Poiret, J. L. M. Palissot (sic!) de Beauvois. *Lamarck Encycl.* **8**: 744–746, 1808.

Thiébaut de Berneaud, A. *Éloge historique de A. M. F. J. Palisot de Beauvois, membre de l'institut de France.* Discours que a remporté le prix de la Société pour l'encouragement des sciences, des lettres et des arts d'Arras in 1821, pp. 1–81, *portr.,* 1821. This was originally published in Mém. Soc. Roy. Arras, 4: 49–116, 1821, but without the portrait. The reprint differs further in having the bibliographic references in scattered footnotes, while in the original they are assembled at the end of the paper, pp. 113–116.

Depping, G. B. Palisot de Beauvois (Ambroise-Marie-François-Joseph). *Biogr. Univ.,* **32**: 412–417, 1822.

Cuvier, G. L. C. F. D. Éloge historique de M. de Beauvois. *Mém. Acad. Sci. France,* **4**: CCCXVIII–CCCLXVI, 1824. Translated into English and published as "Biographical memoir of Baron de Beauvois" Edinb. New Philos. Journ. **1829**: 1–21. 1829.

Quérard, J. M. Palisot de Beauvois. *La France Lit. Dict. Bibl.,* **6**: 563–564, 1834.

Félétz, C. M. D. de. Palisot de Beauvois (Ambroise-Marie-François-Joseph). *Biog. Univ.,* ed. 2, **32**: 14–19, n. d. (about 1857).

Hoefer, J. C. F. Palisot de Beauvois (Ambroise-Marie-François-Joseph, baron de). *Nouv. Biog Gén.,* **39**: 86–88, 1865.

Urban, J. Palisot, Ambroise-Marie-François-Joseph P., baron de Beauvois. *Symb. Antill.,* **3**: 96–98, 1902.

Chase, A. Biographical sketch [of Palisot de Beauvois]. *Contr. U. S. Nat. Herb*, **24**: 210–224, 1925.

Depping also cites an "éloge" of Palisot de Beauvois in the *Rap. Trav. Soc. Agr.* for 1819, published in 1820, a publication I have been unable to trace.

1777 this position was abolished. While occupying this position he apparently devoted considerable time to botany studying diligently under Lestiboudois at Lille, and carrying on both field work and laboratory investigations on the structure and sexual relationships of the cryptogams. Undoubtedly his researches were of value, for as early as 1781, Beauvois, then being resident in Paris, became a correspondent of the Academy of Sciences.

Eager to travel and carry on botanical exploration, he had hoped to take part in the explorations planned by Forskål, with the idea of crossing Africa from the Red Sea to Senegal or Guinea, but this plan, apparently from lack of support, was never consummated. In 1786, however, he associated himself with Captain Landolphe on a journey to the Gulf of Guinea. The object of the expedition was to establish a trading settlement in Owara. He sailed from Rochefort on the "Perou" July 17, 1786. It was apparently his hope that once in Africa he might find a way to consummate his earlier plans of crossing the continent. There seems to have been no intention on his part of entering the service of the company organized to develop the trading station, as he provided his own equipment and supplies. He had expected to be absent about four years, but twelve years actually elapsed before he returned to France.

At whatever ports the ship stopped en route, such as Chamah and Koto on the Gold Coast, he collected natural history material. He reached his destination November 17, 1786. During the years 1786–87 he diligently explored Owara and Benin, sending his collections, as often as possible, to Jussieu in Paris. From a health standpoint the expedition suffered grievously, two hundred and fifty of the original three hundred men succumbing to fever within the first five months, among them Beauvois' brother-in-law and his two European servants. In spite of his own ill health he explored Owara, Benin, and a part of Old Calabar, sending some shipments of plants and insects to Jussieu in Paris. After fifteen months in Africa recurrent attacks of fever so weakened him

that his friend, Captain Landolphe, placed him on a slave ship bound for Haiti.

The vessel remained for a month at Prince's Island, where Beauvois contracted an even more serious illness. The trip to Haiti took three and one-half months, during which time many of the slaves died, as well as two European passengers. Beauvois recovered very slowly and was barely convalescent when the ship reached its destination in July 1788. Here he was received at the home of his uncle, Baron de la Valletière, commandant of the Môle St. Nicholas, and soon recovered from his illness.

Within a few months after his arrival at Haiti he commenced an intensive botanical exploration of the country. His field work, dangerous because of the revolt of the slaves against their white masters, which rendered exploration uncertain, was prosecuted under peculiar difficulties. Conditions becoming more and more critical, he was finally obliged to discontinue his botanical work in order to take part in the discussions of the colonial council, and to command various detachments of troops sent against the rebellious slaves. Between 1788 and 1791, however, he managed to assemble a large herbarium and sent many shipments of seeds to France.

Political conditions becoming progressively worse in Haiti, Beauvois was sent to Philadelphia as a commissioner of the colonial government to solicit food supplies, funds, and, if possible, the intervention of the United States in the affairs of the French Colony, leaving Haiti on October 16, 1791. On January 20, 1792, while residing in Philadelphia, he was elected a member of the American Philosophical Society, the entry reading thus: "Palisot de Beauvois, de la Soc. d. Sc. et Arts du Cap François et Corr. de l'Acad. d. S. de Paris." During the time he was in the United States he collected botanical material as he had the opportunity to do so, from Philadelphia southward.

The records of the American Philosophical Society [1] show

[1] *Early Proceedings of the American Philosophical Society, 1744 to 1838*, i–iii, 1–875, 1884.

that he attended its regular meetings on February 3, 1792, April 18 and August 15, 1794, March 18, 1796, and January 27, February 10, February 17, March 3, and April 7, 1797. These dates indicate four different periods of residence in Philadelphia. That he retained his interest in the Society long after his return to France, is evidenced by an entry, under date of April 15, 1816, that a donation, the amount not indicated, had been received from P. Beauvois.

He returned to Haiti June 24, 1793, just after the burning of Cap Français, to find his house ruined and the natural history collections assembled over a period of three years utterly destroyed, including also his African sketches. He was imprisoned for a time but was fortunate enough, through the intervention of a mulattress whom his uncle had freed from slavery, to escape execution, and to be sentenced instead to deportation to the United States. In the meantime his African collections, which had been left in storage in Owara under charge of Captain Landolphe, were destroyed when the settlement in Africa was plundered by the British in 1791.

Palisot de Beauvois left Haiti a second time on an American ship, which was intercepted by the British who seized all his belongings except one small trunk. He thus landed in Philadelphia a second time utterly penniless. To add to his misfortune his name had been placed on the list of *émigrés* and his estates had been sequestered by the French revolutionary Government. The protests of his friends and family succeeded only in preventing the sale of his possessions. There was no way for him to procure funds from France, and to return, as a proscribed *émigré*, to the reign of terror would have meant death. On his arrival he was received as a guest of Dr. Caspar Wistar, the noted Philadelphian physician. Later he assisted in Peale's museum. It was apparently during this period that he wrote the descriptive catalogue of Peale's collection.[1] At times he supported himself by teaching French and music, and playing in a circus orchestra.

[1] **Palisot de Beauvois, A. M. F. J.** Catalogue raisonné du Muséum de Mr. C. W. Peale. Philadelphia, i–xiv, 1–42, no date. Translated into English and republished by **Peale, C. W.** and **Beauvois, A. M. F. J.** A scientific and descriptive catalogue of Peale's Museum. Philadelphia, i–xii, 1–44, 1796.

Here in spite of the handicap of very meager funds he proceeded to prepare a new herbarium, making also collections of insects, birds, fishes, reptiles, shells, animals, and even fossils. He continued to send to the Paris Museum packets of seeds, some of which reached their destination, others being intercepted in transit. Later the new French minister to the United States, M. Adet, favored him with his support, enabling him to travel for a period of three years in various parts of the country and to assemble more extensive collections of natural history material. His explorations extended from New York to Ohio southward to Georgia, including the southern Appalachians, with a trip into the regions inhabited by the Creeks and the Cherokees, he being authorized to make a study of the fur trade and agriculture of the southern states, to compile statistical data, and to make natural history collections. These collections were lost when the ship on which they were being transmitted to France was wrecked in the vicinity of Halifax. M. Adet, however, had forwarded seeds collected on Beauvois' explorations and on his return to France took with him various living animals that Beauvois had secured for the Paris Museum. Some of his botanical material must have reached France, as certain Palisot de Beauvois United States specimens are still extant.

In the archives of the American Philosophical Society a few letters from Palisot de Beauvois are preserved. One, addressed to Dr. Caspar Wistar, was written at Charleston, South Carolina, May 20, 1796, from which we learn that Beauvois had just arrived from Savannah, where he had found no new animals or minerals, but had collected a great many undescribed plants, although no new genera were represented. He notes that he there met Michaux, who had just returned from an eleven months' stay in the Cherokee country, and had made a great collection of plants in that region. In a letter written in Richmond, Virginia, April 25, 1798, addressed to Thomas Jefferson, he discussed chiefly the animals and fossils that he had observed, explaining that he was incorporating the data in the form of a letter because of his

uncertainty as to whether or not Jefferson would be in Philadelphia when he returned in order to take passage to France. He spoke of the extreme richness of vegetation of the regions that he had visited.

Eventually his friends in France succeeded in having Beauvois' name removed from the list of *émigrés* and he was permitted to return. He accordingly abandoned his plans for further travel in the Arkansas region beyond the Mississippi River and returned to France, landing at Bordeaux in August, 1798, after an absence of twelve years. From the time of his return until his death, January 21, 1820, he busied himself with the study of grasses, various groups of cryptogams, and with that part of his African collection of plants and animals that he had sent to Jussieu before leaving Owara for Haiti. He prepared and published many short papers and several larger ones, notably his work on the grasses and the folio works on the plants and insects of Owara, leaving, however, a number of unfinished and hence unpublished manuscripts. A bibliography of his publications is appended to this paper.

That Palisot de Beauvois was deeply interested in natural science is manifest. Few individuals in a similar position, subjected to the vicissitudes that he endured, would have had the courage and persistence to continue their investigations. Only the field naturalist who is interested in studying his own collection from regions previously unexplored, or at most only inadequately known, can fully appreciate the tragedy of losing one's collections through no fault of his own, and Palisot de Beauvois lost three great collections of plants and other natural history material made between the years 1786 and 1798—the Owara and Benin collections destroyed in Africa in 1791; the Haitian collection, burned at Cap Français, Haiti, in 1793; and the greater part of the United States collections, lost at sea near Halifax in 1798. But for these repeated misfortunes, his name undoubtedly would have been a very important one in the early studies of the floras of Haiti and of the eastern United States. As it is, the name Palisot de

Beauvois rarely appears in the special botanical literature pertaining to North America. He lived in Philadelphia for many months, at four different times between 1791 and 1798, and yet a modern Philadelphian writing extensively on the botanists of that city, was apparently unaware of this contributor to the history of the science in Philadelphia in spite of the fact that Beauvois' first botanical papers were written in Philadelphia and published in the *Transactions* of this society. Palisot de Beauvois died in Paris, January 21, 1820, at the age of sixty-eight.

Some of Palisot de Beauvois' botanical collections are still extant, being largely preserved in the herbarium of the Jardin botanique at Geneva, Switzerland.[1] Professor M. L. Fernald, Curator of the Gray Herbarium, informs me that there are scattered specimens in that great reference collection, received many years ago from Paris, the collector being indicated merely by the initials "P. B." There are some sheets in the herbarium of the Philadelphia Academy of Natural Sciences, marked "Beauv." Those that I have examined, my attention having been called to them by Dr. F. W. Pennell, were all from British India, a region Beauvois never visited. They doubtless represent collections made by other individuals, transmitted by Beauvois in all probability to the American Philosophical Society.

Palisot de Beauvois' interests were wider than the field of natural history. Quérard states that he was the author of several plays, among them one entitled "Du Railleur" which was not unworthy of presentation, a comedy in verse, in five acts. I have personally seen no works of this type by Palisot de Beauvois nor have I located other bibliographic references to them. It is, of course, possible that the contemporary dramatist Palisot de Montenoy (1730–1814) may have been confused with Palisot de Beauvois, although the title "Du Railleur" does not appear in any bibliography of Palisot de Montenoy that I have seen. Of more interest perhaps,

[1] **Hochreutiner, B. P. G.** Reliquiae Palisotianae ou collections et notes manuscrites inédites rapportées d'Oware et de Benin par Palisot de Beauvois. *Ann Conserv. Jard. Bot. Genève*, **2**: 79–101, 1898.

from a purely literary standpoint, is the probability, or at least the possibility, that Palisot de Beauvois was the author of the anonymous "Odérahi," [1] a work that had considerable vogue in the early part of the last century. By some its authorship has been accredited to Chateaubriand.

"Odérahi" is discussed in considerable detail by Chinard,[2] who however at that time did not know of the earlier edition of 1796, having examined a copy of the 1801 edition in the Newberry Library, Chicago. He informs me that there is also a copy in the New York Public Library and one at the University of Michigan. This was followed up by Giraud,[3] who located a copy of the second edition of Veillées américaines, 1796, in Paris. He states that there are 17 "parts" in the three volumes, the first 6 including "Eliza," the 7th "Eugenie" and the last 10 "Odérahi," the latter republished in 1801. He notes further that the introductory and explanatory statement "Le cultivateur à ces Veillées" is signed "P. B." Dr. Chinard has recently located a copy of this work in the John Carter Brown Library. The first edition of this work seems to be unknown. Hazard [4] later considered the case and concluded that Palisot de Beauvois rather than Chateaubriand was the author of "Odérahi." To the title of the edition of 1801 is added the phrase "Odérahi est la soeur aînée d' Atala"; Chateaubriand was the author of Atala.

[1] **Odérahi,** histoire américaine; contenant une peinture fidelle des moers des habitans et d'intérieur de l'Amérique septentrionale. Odérahi est la soeur aînée d'Atala. Paris. 1801. First printed as one of the stories in "Veillées américaines," ed. 2, 1796. Spanish translation: "Oderay. Usos, trages, ritos, costumbres y leyes de los habitantes de la América septentrional, traducidas del Francés é ilustradas con varias notas críticas por Don Gaspar Zavala y Zamora," pp. 1–288, 1804. German translation: "Oderahi, eine amerikanische Erzahlung. Seitenstuck zur Atala. Von demselben Verfasser. Aus dem Franzosischen ubersetzt," 1–x, 1–412, 1803. The second edition of the "Veillées américaines" consists if three 12 mo. volumes, **1**: 1–192; **2**: 1–202; **3**: 1–196, 1796. The text of "Odéraï" commences on page 69 of volume two, with the heading "Septième Veillée. Odéraï"

[2] **Chinard, G.** Une soeur ainée d'Atala. Odérahi, histoire américaine. *Rev. Bleue*, **1912** (2): 779–785, 1912.

[3] **Giraud, V.** Les Veillées américaines. Contribution á l'histoire des sources d'Atala. *Rev. Bleue*, **1913** (1): 154, 1913.

[4] **Hazard, P.** L'auteur d' "Odérahi" histoire américaine. *Rev. Lit. Comp.*, **3**: 407–418, 1923

Quérard's statement regarding Palisot de Beauvois' authorship of certain plays was based on Thiébaut de Berneaud's "Éloge historique." Palisot de Beauvois was a rather voluminous writer on natural history, at times somewhat of a pamphleteer, apparently the author of several plays, and thus may well have been the author of the romances forming the "Veillées américaines." If he really be the author of the latter, then it is rather strange that Thiébaut de Berneaud did not know of it, because he must have been rather intimately acquainted with Palisot de Beauvois, and he had access to the latter's published and unpublished writings. One wonders why the author of a romance that attracted sufficient attention on the occasion of its second printing soon to be translated into both Spanish and German, should elect to remain anonymous.

Palisot de Beauvois' "Flore d'Oware et Benin en Afrique"

In my copy of the "Flore d' Oware et Benin" six of the original twenty fascicle covers are preserved. These are as follows: (1) titles, vii–xii, 1–8, *t. 1–6*, 1805; (10) *t. 55–60*, 1806; (11) *t. 61–66*, 1808; (12) *t. 67–72*, 1810; (13) *t. 73–78*, 1810; and (20) *t. 115–120*, 1820.

The set in the library of the British Museum, Natural History, contains the fascicle covers for number 7 (*t. 37–42*, 1806) and 12 (*t. 67–72*). Hallier[1] quoted by Stapf[2] records the publication dates for fascicles 1 to 6, *t. 1–36* as 1805, 7 to 10, *t. 37–60*, 1806, 11, *t. 61–66*, 1808, 12, 13, *t. 67–78*, 1810, from the copy in the library of the Botanical Museum, Hamburg. Stapf also cites a reference in Flora, **5**: Beibl. **1**: 4, 1882, to the effect that 17 fascicles had been published by 1818. For these references I am indebted to Sir Arthur Hill, Director of the Royal Botanic Gardens, Kew. Copies of the work in the libraries of the New York Botanical Garden, the Arnold Arboretum, the Boston Society of Natural History,

[1] *Jahrb. Hamb. Wiss. Anst.*, 17: 67, 1899.
[2] *Kew Bull.* 126, 1820.

Philadelphia Academy of Natural Sciences, the United States Department of Agriculture, the American Philosophical Society, and two copies in the Department of Printed Books, British Museum (one in the library of King George III, one in the library of Sir Joseph Banks) contain no fascicle covers. The appended consideration of the dates of issue of the parts of the "Flore d'Oware et Benin" (p. 914) is by Dr. J. H. Barnhart, bibliographer, New York Botanical Garden. From the data that he has critically compiled it is evident that the livraison dates are, in some cases, as untrustworthy as are the title page dates.

Bibliography of Palisot de Beauvois

Because of the rather widely scattered nature of Palisot de Beauvois' publications, it has been a difficult task to compile the following list. The basis of it consists of the entries in the Royal Society of London "Catalogue of Scientific Papers." In the *Magasin Encyclopédique* from 1800 to 1815 a number of items occur which have not been included. They appear, without titles, in the secretaries' reports of the proceedings of the "Institut National." In the "Tableau générale" to the journal, titles are sometimes given under Beauvois' name, such as "Observations sur différentes espèces de mousses," "Recherches sur les plantes appelées cryptogames," "Sur la fécondation des mousses," "Sur la famille des lycopodes," and "Sur la fructification des mousses." They include a summary of Beauvois' remarks and comments of other botanists who took part in the discussions.

1. First memoir of observations on the plants denominated cryptogamic. *Trans. Amer. Phil. Soc.*, **3**: 202–213, *1 t*, 1793.
2. Catalogue raisonné du Muséum de Mr. C. W. Peale, i–xiv, 1–42. Philadelphia, no date [1795?].
3. **& Peale, C. W.** A scientific and descriptive catalogue of Peale's museum. Philadelphia, i–xiv, 1–44, 1796.
   An English edition of the preceding work.
4. Translation of a memoir on a new species of Siren. *Trans. Am. Phil. Soc.*, **4**: 277–281, *1 t.*, 1799.

5. Memoir on the subject of a new plant growing in Pennsylvania, particularly in the vicinity of Philadelphia. *Trans. Am. Phil. Soc.*, **4**: 173–177, 1799.
6. Memoir on Amphibia. *Trans. Am. Phil. Soc.*, **4**: 362–381, *1 t.*, 1799.
7. Sur le renard de le lapin d'Amérique. *Bull. Soc. Philom.*, **2**: 137–138, 1800.
8. Notice sur le peuple de Bénin, lue à la séance publique de l'Institut du 15 nivôse, An ix. *Décad. Philos.*, 30 fructidor, An ix, 513–518, 1801.
9. Extrait d'un Voyage chez les Creecks et chez les Chérokées. Lu à l'Institut national dans la séance publique du 15 messidor. *Décad. Philos.*, 20 messidor, An ix, 94–103, 1801.
10. Mémoire sur un nouveau genre d'insectes trouvé en Afrique. Lu à l'Institut national dans sa séance du 16 thermidor et à la société philomatique le 23 du même mois. *Décad. Philos.*, 30 fructidor, An ix, 513–518, *1 t.* Reprint 1–6, *1 t.*, 1801.

For a long discussion of this paper see Schenkling, S. *Entomol. Mitt.*, **3**: 318, 1914. Through error its place of publication has been indicated by some authors as the *Magasin encyclopédique.*

11. Prodrome de l'Aethéogamie ou d'un Traité sur les familles de plantes dont la fructification est extraordinaire; famille des mousses. *Mag. Encycl., ix Ann*, **5**: 289–330, 1804.
12. Mémoire sur une nouvelle plante recueillie à Owarre, en Afrique. Lu à la Classe des sciences physiques et mathématiques de l'Institut, le 16 vendémiaire, An xiii. *Décad. Philos.*, 10 pluviose, An xiii, pp. 198–205, 1805.
13. Suite de l'Aethéogamie. Sixième famille. Les Lycopodes. *Mag. Encycl., ix Ann*, **5**: 472–483, 1805.

The name Aethéogamie was proposed as a substitute for the Cryptogamia. Seven families were recognized on which Palisot de Beauvois proposed to publish successively. The one on the mosses was the fifth family, and the one on the lycopods was the sixth. The others, except the first family, seem not to have been published. The above two were combined and issued in reprint form under the next title.

14. Prodrome des cinquième et sixième familles de l'Aethéogamie. Les mousses. Les Lycopodes. I–II, 1–114, 1805.

A reprint of items 11 and 13.

15. Prodromus of Aetheogamia, or a treatise on those families of plants whose fructification is extraordinary. *Ann. Bot. Konig & Sims*, **2**: 218–244, 1806.
16. Continuation of the Aetheogamia. The Lycopodia. *Ann. Bot. Konig & Sims*, **2**: 244–251, 1806.

This and the preceding item, translated from the originals in the *Magasin encyclopédique*, 1805.

17. Flore d'Oware et de Benin en Afrique, **1**: i–xii, 1–100, *t. 1–60*, 1805–1810?; **2**: 1–95, *t. 61–120*, 1810?–21.

See p. 914 for dates of issue of the various fascicles.

18. Insectes recueillis en Afrique et en Amérique, dans les royaumes d'Oware et Benin, à Saint-Domingue et dans les États-Unis, pendant les années 1786–1797. i–xvi, 1–276, *t. 1–90*, 1805–21.

This was planned to be published in 30 livraisons but due to the author's death only 15 appeared. The 15th part, pages 241–276, was edited by M. J. G. Audinet-Serville.

19. Sur les champignons en général, et particulièrement sur quelques espèces peu et mal connues. *Ann. Mus. Hist. Nat. [Paris]*, **8**: 334–346, *t. 57*, 1806.
20. Mémoire sur les Palmiers en général, et en particulier sur un nouveau genre de cette famille. *Journ. Bot. Desvaux*, **2**: 74–87, 1809.
21. Observations sur les Champignons et sur leur manière de croître. *Journ. Bot. Desvaux*, **2**: 147–165, 1809.
22. Nouvelles observations sur la fructification des Mousses et des Lycopodes. *Journ. Phys.*, **73**: 89–109, *t. 1*, 1811. Reprint 1–32, *t. 1*, 1811.
23. Notice sur une nouvelle expérience relative à l'écore des arbres. *Journ. Phys.*, **73**: 209–212, *t. 1*, 1811.
24. Notice sur la Napoleona imperialis, premier genre d'une nouvelle famille de plantes. *Mém. Soc. Nat. Moscou*, **1**: 65–66, 1811.

25. Éloge historique de M. Fourcroy, conseiller d'état à vie, pp. 1–38, 1811.

26. Essai d'une nouvelle agrostographie; ou nouveaux genres des Graminées, avec figures représentant les caractères de tous les genres. [i-vi] i–lxxiv, pp. 1–182, Atlas 1–16, *t. 1–25*, 1812.

For a recent critical consideration of the genera and species included see **Niles, C. D.**, "A bibliographic study of Beauvois' Agrostographie with introduction and botanical notes by A. Chase." *Contr. U. S. Nat. Herb.*, **24**: i–xix, 135–214, 1925. Beauvois' personal extensively annotated copy of the "Nouvelle agrostographie" is in the library of the United States Department of Agriculture, Washington, D. C.

27. Lettre de M. Palisot de Beauvois à J.-C. Delamétherie, sur les plantes dormeuses. *Journ. Phys.*, **74**: 121–124, 1812.

28. Premier (et second) mémoire et observations sur l'arrangement et la disposition des feuilles; sur la moëlle des végétaux ligneux; et sur la conversion des couches corticales en bois. *Mém. Inst. France*, **1812** (2): 121–162, *t. 1–4*, 1812. Reprint 1–41, *t. 1–4*, 1812.

This is summarized in *Journ. Phys.*, **81**: 389–392, 1815.—lu le 20 avril 1812.—Second mémoire sur l'arrangement et la disposition des feuilles.—lu le 6 juillet 1812.

29. Lettre de M. Palisot de Beauvois, membre de l'Institut a M. Desvaux, rédactieur du Journal de Botanique. *Journ. Bot. Desvaux*, **3**: 12–14, 1813.

In the table of contents this is listed as: "Sur une espèce de Champignons appartenant au genre Merulius."

30. Compte rendu à la classe des sciences physiques et mathématiques de l'Institut, de la seconde partie de l'ouvrage intitulé: Muscologiae recentiorum supplementum de M. Bridel. *Journ. Bot. Desvaux*, **4**: 153–157, 1813.

31. Mémoire et observations sur les plantes de la famille des Cypérées. *Mém. Inst. France*, **1812** (2): 51–58, 1814.

32. Réfutation d'un écrit anonyme intitulé: Resumé du temoignage . . . touchant la traite des nègres, adressé aux différentes puissances de la chrétienté, pp. 1–56, 1814.

33. Sur les organes de la fructification des Mousses. *Bull. Soc. Philom.*, **4**: 130–134, 1814.

34. Lettre de M. Palisot de Beauvois à M. Delamétherie. Extrait de la notice lue à la classe des Sciences Physiques et Mathématiques de l'Institut, dans la séance du 27 juin 1814, suivie de quelques Réflexions ultérieures sur les organes de la fructification des mousses. *Journ. Phys.*, **76**: 5–15, 1814.
35. Mémoire et observations sur l'arrangement et la disposition des feuilles. *Journ. Phys.*, **81**: 389–393, 454–459, 1815.
36. Mémoire sur les Lemna, ou Lentilles d'eau, sur leur fructification et sur le germination de leurs graines. *Journ. Phys.*, **82**: 101–115, *t. 1*, 1816.
37. Description d'une aggrégation de pierres observée dans la Caroline du Nord, États-Unis d'Amérique, et connue dans le pays sous la dénomination de mur naturel (natural wall). *Mém. Acad. Sci. Paris*, **3**: 109–120, *t. 1*, 1818.
38. Muscologie, ou traité sur les mousses. *Mém. Soc. Linn. Paris*, **1**: 388–472, *t. 1–11*, 1822. Reprint 1–88, *t. 1–11*, 1822.

Palisot de Beauvois contributed a considerable number of articles to Lamarck's *Encyclopédie méthodique*, and the *Dictionnaire des sciences naturelles*. For references to other publications in the form of fiction, probably or possibly the work of this author, see p. 907.

On the Dates of Publication of Palisot de Beauvois' "Flore d'Oware et Benin en Afrique"[1]

As the title-pages of each of the two volumes of this work bear erroneous dates, and even the dates printed on some of the fascicles or "livraisons" in which it appeared are not reliable, it becomes a matter of much interest to search contemporary literature for occasional references that may shed light upon the actual dates of issue.

Misdating began with the appearance of the very first fascicle. The title-page of Vol. 1, which was contained in

[1] Contributed by John Hendley Barnhart, Bibliographer, New York Botanical Garden.

livr. 1, was dated "1804," but the cover bore the date "1805." Both could not possibly be correct, and we shall see that the later date is the true one. The work was announced by Jussieu in *La décade philosophique*, no. 10, for the second quarter of "An xii." This quarter began 23 December 1803 and ended 21 March 1804, and no. 10 certainly appeared not later than April 1804. Jussieu says that he had seen the six plates of livr. 1 and describes them; but he does not say that they were already published, and they certainly were not, for his remarks were printed in and comprise pages vii and viii of livr. 1 as issued. An extensive quotation from Jussieu's announcement was translated into English and published in the *Annals of Botany* (Konig & Sims), **1**: 182–185, in the number of 1 May 1804. The statement was there made that Jussieu's announcement was "a review of the first number, which *had already appeared* in France." This is surely a misinterpretation of Jussieu's statement that he had seen the six plates, but it has lent credence to the erroneous assumption by some authors that livr. 1 actually appeared in 1804.

The first actual notices of the publication of the work seems to have been that in the *Gött. Gelehrte Anz.* for 2 September 1805 (**1805**: 1393–1397), where livr. 1 ("1805") is described as comprising xii + 8 pages and 6 plates, and its contents fully detailed. There is also a very complete account of the "Prém. Livraison," 1805, in *Neues Jour. Bot.* (Schrader), $\mathbf{1}^2$: 61–72, 1806. This says that it consisted of xii + 8 pages, large quarto, with 6 colored plates and a blue (!) cover, and gives in German much of Jussieu's announcement and a full account of both plates and text.

Livr. 1–4 are known to have been dated 1805 and there is contemporary evidence that this date is correct. Of these Livr. 2 and 3 were reviewed by Jussieu, *Décade Philos.*, 20 prairial, An xiii, 3^{me} Trimestre, pp. 449–451, and *Décade Philos.*, 10 fructidor, An xiii, 4^{me} Trimestre, pp. 385–389; these dates correspond to about May 21 and August 30, 1805. The first four livraisons were reviewed in *Phys.-ökon. Bibliothek*, **23**: 329–332, 1806. This was the first number of this

journal to bear the date 1806, and the review was presumably written before the end of the year 1805. It may be remarked in passing that *Myrianthus* (concluding the second fascicle) was cited by Willdenow (Sp. Pl. **4**: 598) in 1806.

Livr. 5 and 6 were dated 1805, and the former, at least, probably appeared in that year. In any event, pages 47 and 48 and plates 27 and 29 (in livr. 5) were cited by Persoon (Syn. Pl., **2**: 173) in 1806, and page 59 and plate 36 (in livr. 6) by the same author (Syn. Pl., **2**: 586) in the following year (1807).

Livr. 7–10, completing volume 1, were all dated 1806, but at this point there seems to have been some serious interference with the appearance of the work. We have testimony, apparently independent, from two different sources that livr. 7 did not make its appearance until 1809. In the number of the *Gött. Gelehrte Anz.* for 2 September 1809 (**1809**: 1385–1391) is an account of livr. 2–7, 1805–1809, each containing 6 plates (Pl. 7–42). And in the same year livr. 2–7 are fully described, with no hint that livr. 8 had yet appeared, in *Neues Jour. Bot.* (Schrader), **3**: 90–108. Livr. 8, 9, and 10 may possibly have appeared in quick succession, or even all together, but the date printed on their covers, 1806, is surely not to be credited.

Livr. 11, commencing the second volume, resembles the first in certain respects. It contained the second title-page, dated 1807, while its cover bore the date 1808; but in this instance both dates seem to have been far out of the way. There is no reason to suppose (although it is possible) that the second volume was begun before the first was completed, and as it is doubtful that the first was finished in 1809, the earliest date that can reasonably be assigned to livr. 11 is 1810, and even this is questionable.

Livr. 12 was certainly not printed before the last quarter of 1809, for on page 15 there is mention of a paper read before the Institut de France, 25 September 1809. The cover-date of this fascicle is 1810, and this may be accepted as correct as confirmed by Desvaux's review of Vol. 1 and the first two

livraisons of Vol. 2, in January 1811 (*Mercure de France*, **46**: 58–65).

Livr. 13 is also dated 1810, and this may be correct, although it is very doubtful.

Livr. 14 was certainly not published before 1812, for it contains a reference, in a footnote on page 35, to Palisot de Beauvois' own *Essai d' une nouvelle agrostographie*, issued in that year. It may not have appeared until several years later, but certainly not later than 1817, and it is strange that de Candolle, when he monographed the genus *Uvaria*, in the first volume of his *Systema* (1818), makes no mention of *Uvaria Chamae*, described in this fascicle.

Livr. 15 cites (page 51) Palisot de Beauvois' own paper on *Lemna*, published in the *Journal de Physique* for February 1816. This fascicle may have appeared during the same year; surely before the end of 1817. It is quite possible that livr. 14 and 15 were issued together as a "double fascicle," as seems to have been the case with the two following ones.

Livr. 16 and 17 were almost certainly issued together, in 1818, and probably under a single cover. The *Bibliographie de la France*, so useful for French publications of this period, never mentioned the "Flore d'Oware" directly, but in the number for 29 November 1817 (**6**: 645, 646) appears an account of a "Prospectus de deux ouvrages." These two works were: (1) La flore d'Oware et de Benin; folio, 15 livr. have appeared, and there will be at least 24; XVI and XVII to appear in January 1818. (2) Insects recueillis en Afrique, à Saint-Domingue et dans les États-Unis; 10 livr. have appeared, and there will be at least 30; XI and XII to appear in March (1818). This makes it clear that late in 1817 livr. 16 and 17 were in such an advanced state that they were promised for the following January, and if they did not actually appear at that time they were probably not delayed more than a few months. Flora, in 1822 (**5**: Beil. 4), in a list of recent French botanical literature, says of the "Flore d'Oware": "Paris 1805–1818. Livraisons I–XVII." (It is a little strange that the compiler of this list had not heard of

the completion of the work; but this is fortunate as it supplies confirmation of the date 1818 for livr. 17.)

Livr. 18 and 19 probably appeared together in 1819 or 1820, but there seems to be no direct evidence upon this point.

Palisot de Beauvois died in January 1820. The final livraison (20) had not then made its appearance, yet it contains no reference to his death. It must have been in an advanced stage of preparation, and was dated 1820, yet it does not seem to have been published until the following year. Quérard, the famous French bibliographer, who was living at the time and much interested in matters of this kind, says (*Fr. Litt.*, **6**: 563): "La Flore d'Oware et de Benin avait été promise en 20, au plus 25 livraisons: il n'en a été publié que 20, dont dernière, qui n'a paru qu'en 1821, ne termine pas l'ouvrage. Chaque livraison, composée de six planches, a coûté, par souscription: en noir, 12 fr., et, figures coloriées, 24 fr."

Livr Nos.	Pages approx.)	Plates	Dates on Covers	True Dates
1	1: titles, vii–xiii, 1–8	1–6	1805	1805
2	1: 9–16	7–12	1805	1805
3	1: 17–32	13–18	1805	1805
4	1: 33–40	19–24	1805	1805
5	1: 41–48	25–30	1805	1805?
6	1. 49–60	31–36	1805	1806?
7	1: 61–72	37–42	1806	1809
8	1: 73–80	43–48	1806	1809
9	1: 81–88	49–54	1806	1810?
10	1: 89–100	55–60	1806	1810?
11	2: titles, 5–12	61–66	1808	1810?
12	2. 13–24	67–72	1810	1810
13	2: 25–32	73–78	1810	1811?
14	2: 33–44	79–84		1813?
15	2: 45–52	85–90		1816?
16/17	2: 53–72	91–102	1818	1818
18/19	2: 73–84	103–114		1819?
20	2: 85–95	115–120	1820	1821

Original covers of livr. 1–13 and 20 are known to exist, but, with the exception of livr. 1, the pages in each fascicle

can only be guessed. Each is known, however, to have contained six plates, and these appeared in the sequence in which they were numbered; it is also certain that the text in each livraison corresponded with the plates in so far as this was possible without breaking signatures. We can, therefore, approximate, with little danger of serious error, the pagination of each fascicle, and we may summarize our knowledge of the work as shown in the table on the opposite page.

In view of the abundant internal and collateral evidence that the title-pages do not bear correct dates, the dates of publication assigned to genera here appearing as new, in various nomenclators, are weird in the extreme. The more important ones are summarized in the following table; these

Livr. Nos.	True Date	New Genus	Pfeiffer, Nomenclator	Index Kewensis	Dalla Torre & Harms	Post & Kuntze
1	1805	Culcasia	1805	1805	1804	1804
		Omphalocarpum	1805	1805	1804	1805
2	1805	Myrianthus	1805	1805	1804	1805
3	1805	Ventenatia	1805	1805	1804	1805
5	1805?	Spathodea	1805	1805	1804	1805
6	1806?	Landolphia	1806	1806	1806	1806
7	1809	Anthonotha	1805	1805	1804	1804
8	1809	Raphia	——	1804	1804	1804
9	1810?	Lasianthera	1805	1805	1804	1804
10	1810?	Ormocarpum	1805	1805	1804	1805
11	1810?	Ceranthera	1805	1805	1807	1805
12	1810	Cryphiospermum	1805	1805	1805	——
13	1811?	Stipularia	1805	1805	1807	1805
		Napoleona	1807	1805	1807	1805
16/17	1818	Platostoma	1805	1805	1807	1805
		Brillantaisia	1805	1805	1807	1805
18/19	1819?	Hylacium	1807	1807	1807	——
20	1821	Kolbia	1807	1807	1807	1810

are (1) Pfeiffer's Nomenclator (often more reliable in the matter of dates than later works); (2) Index Kewensis; (3) Dalla Torre & Harms' Index; (4) Post & Kuntze's Lexicon.

There must be some collateral evidence that has escaped my notice to the effect that *Landolphia* was published in 1806 (as I believe that it was), since all the authorities agree

upon this year, although they return to earlier years in the case of genera published in later fascicles.

Raphia was described in a paper read before the Institut de France in 1806; this paper was published in full in *Jour. Bot. Desv.*, **2**: 74–87, 1809; according to a footnote (on page 79) the genus had meanwhile been published in the Flore d'Oware. This makes the date 1809 fairly certain for livr. 8, as livr. 7 was not issued until that year.

HARVARD UNIVERSITY,
April, 1936.

PALISOT DE BEAUVOIS

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MARINE MOLLUSCAN PROVINCES OF WESTERN NORTH AMERICA [1]

HUBERT G. SCHENCK AND A. MYRA KEEN

ABSTRACT

Provinces are areas containing distinctive assemblages of species. Because authors disagree on the number and size of West American molluscan provinces, distributions of 1,948 species of mollusks are here analyzed statistically to disclose what provincial divisions of the region are justified. Four provinces are evident: a Panamic ending on the north at Cape San Lucas, Lower California; a Californian extending from there to Puget Sound, overlapping an Aleutian, which begins at the California-Oregon line and extends north to Scammon Bay, Alaska (latitude 62° N.); the Aleutian is in turn overlapped by an Arctic province, which begins in the Alaskan Gulf area and extends indefinitely northward. These results are shown graphically on a map of North America, where they are compared with the conclusions of other workers.

INTRODUCTION

THE FACT of differential geographic dispersal of organisms is observational, but the size of circumscribed areas is a matter of interpretation. Woodward's [2] molluscan provinces, usually accepted as a fair approximation of the facts, are not sharply-defined; Tryon (1882, p. 153), Cooke (1914, p. 105), and many other authors have demonstrated that in reality boundaries are often crossed by species held by cabinet-naturalists to be restricted to their respective areas. It does not follow, however, that zoögeographical provinces are imaginary simply because the boundaries between adjacent ones are difficult to detect. The difficulty may be entirely the fault of ill-chosen criteria for defining them. Since no investigator has employed biometrical methods for their derivation, the present paper constitutes the first attempt, so far as we have been able to determine, to apply statistics

[1] Read in part under the title "West American Marine Molluscan Provinces" before the Pacific Section of the Paleontological Society, Stanford University, California, April 13, 1935; abstract in *Proceedings of the Geological Society of America* for 1935 (1936).

[2] Among the authors who have discussed the zoögeography of the Recent marine mollusks are Lovén (1846), Middendorff (1851), Gould (1852), and Woodward (1856). The molluscan provinces of the last-named writer are those most widely accepted today.

to the interpretation of the size of certain zoögeographical provinces. The result of the attempt is the proposal of a method of dividing the eastern North Pacific Ocean into molluscan provinces separated by overlap areas.

Acknowledgments

For aid in the preparation of the data sheets, completed in 1923, we are indebted to Robert E. Schenck. Nothing more than a crude graphical analysis of these sheets was attempted by the senior author in an unpublished manuscript until, in 1934, the junior author began a biometrical analysis of the material. Many facts and citations to the literature have been assembled by correspondence and conversation with numerous biologists and paleontologists. We should like to acknowledge especially the coöperation of the following: C. C. Church, Alexander Clark, Hubert Lyman Clark, C. K. Fisher, D. L. Frizzell, U. S. Grant, IV, L. G. Hertlein, H. N. Lowe, G. F. McEwen, Lois T. Martin, J. Marwick, Mary J. Rathbun, W. H. Rich, A. M. Strong, F. W. Weymouth, George Willett, W. P. Woodring, and Harry Yocum. Specimens from critical localities were supplied through the courtesy of C. M. Carson, Mr. and Mrs. E. P. Chace, Lois R. Fraser, J. Hollister, H. N. Lowe, H. MacGinitie, and H. C. McMillin. Pertinent suggestions for the improvement of the typescript were offered by D. L. Frizzell, H. D. Hedberg, P. W. Reinhart, and W. Egbert Schenck.

Material Studied

We have collected marine mollusks, both Recent and fossil, from Washington to southern California and we have had at our disposal several thousand shells collected by others from the Arctic to Panama; these specimens were segregated according to collecting station. This collection comprises about 36 per cent of the species catalogued by Dall (1921) in the paper that serves as the basis of our biometrical analysis.

Definition of Faunal Province

Sclater (1858, pp. 131–132), basing his conclusions upon the distribution of birds, used "the amount of similarity or dissimilarity of organized life solely as our guide" in ascertaining the "primary ontological divisions of the earth's surface." Woodward (1856, p. 349) said that "in order to constitute a distinct province it is considered necessary that at least *one-half* of the species should be *peculiar*." Wallace (1894) appreciated the fact that zoological regions, though strictly natural, are more or less conventional, "being established solely for the purpose of facilitating the study of existing geographical distribution of animals."

On the basis of such definitions, even if complete and correct distribution data were available, the objective determination of provinces would be difficult. The provincial areas proposed, moreover, do not always fulfill their authors' requirements. For example, along the west coast of North America, Woodward's Californian province is the only one which even approaches 50 per cent peculiarity. We propose, therefore, to substitute the following definition:

A marine molluscan province is a subdivision of a region, subregion, or realm, populated by a distinctive assemblage of species. Distinctiveness is not simply a matter of ecologic situation but of spacial extent or range. A province has at its center a high percentage of species with restricted ranges; the periphery, on the contrary, is marked by species of wide distribution. The size of a province being variable, its limits are best defined by statistical methods.

Biometrical Analysis of the Distribution of Recent Species

Introduction.—The west coast of the Americas is unique among coast-lines of the world in that its sweep from the Arctic Circle to the Antarctic is little broken by embayments. Therefore, a statistical summary of distribution can be made directly from any reliable check-list of species-ranges by translating localities into latitudes. We have made such an

analysis for the Mollusca, using the list prepared by Dall (1921). This is a list of the ranges of all mollusks (excepting the Cephalopoda) reported between Icy Cape, Alaska, and San Diego, California.[1]

Preparation of Data.—We plotted on graph-paper the latitudinal ranges of 1,948 species of Pelecypoda, Gastropoda, and Scaphopoda. A sample data sheet for the genus *Cadulus* is shown in figure 1.

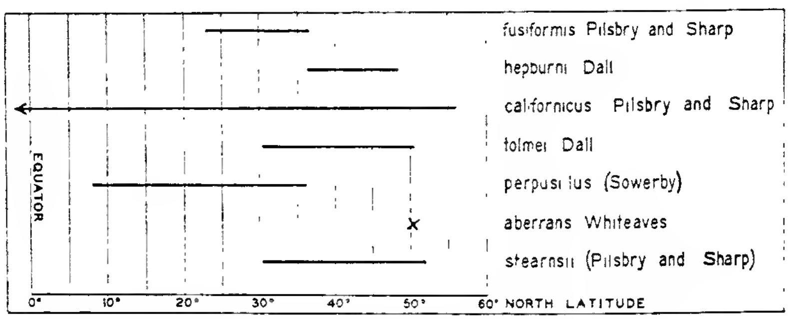

FIG. 1. Sample data sheet for the genus *Cadulus*. The range given by Dall (1921) for each species is plotted on a latitude scale.

The range for each species is represented by the straight line connecting the two end-points of range given by Dall (1921). We have tried to minimize errors and ambiguities of the original record by adding all available corrections and extensions of range, and by omitting such records as "Range: California."

Treatment of Data.—Statistically, no single method will completely summarize the data. We have, therefore, used three methods of analysis corresponding to the three most important qualities of a straight line: the location of the center, the length, and the locations of the ends. For convenience, we shall call these methods 1, 2, and 3. Method 1, *mid-points of range*, is probably the best single index of the locus of a given species, corresponding roughly to its center of radiation. Method 2, *total distribution*, is separating the line

[1] This must not be interpreted to mean that our data end with the latitude of San Diego, since, on the contrary, some mollusks found at that place, as well as elsewhere to the north, range considerably farther south.

into convenient units for counting (designated hereafter as *latitude-intervals*) and collating these units for the entire array of species, assuming that the distribution of any species between its known end-points of range is relatively continuous. Finally, method 3, *end-points of range*, is counting the number (or percentage) of species at each latitude-interval whose end-points fall within the limits of a progressively widened series of bands; for example, ten per cent of the species occurring at a given latitude may have a latitudinal range of less than two degrees in either direction, twenty per cent may have a range of less than four degrees, and so on.

Results.—The results of these three methods of analysis are shown graphically in figures 2, 3, and 5, respectively. The x-axis (latitude) is drawn to the same scale in all three charts, with the equator (0°) at the left. The y-axis in figure 2 is in terms of actual numbers (raw frequency), in

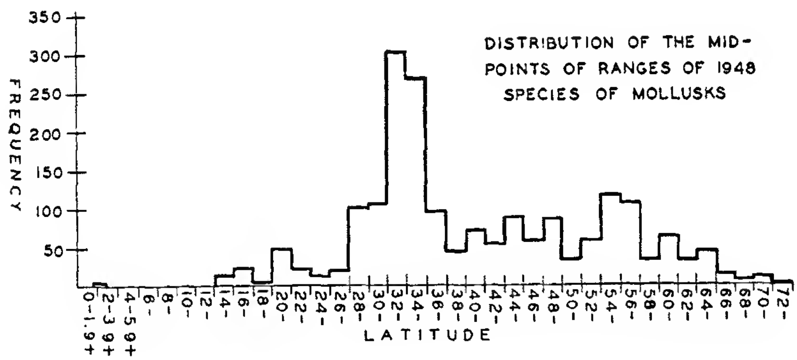

FIG. 2. Distribution of the mid-points of ranges of 1,948 species of West American mollusks. About 300 species have their centers of range in the Los Angeles region (33° N. Lat.); only about 90 species at Puget Sound (48° N. Lat.).

figure 3 of percentage-frequency, and in figure 5 of a measure to be discussed later.

Method 1: Mid-points of Ranges.—Figure 2 gives the distribution of the mid-points of ranges of 1,948 species of mollusks in Dall's (1921) list. The curve reads as follows: the Los Angeles area (latitudes 32°–34°) bisects the ranges of

300 species; the Cape Mendocino area (latitudes 40°–42°) is the middle-of-range of 74 species; the Forrester Island-Aleutian Island area (latitudes 56°–58°) of 107 species, and so on.

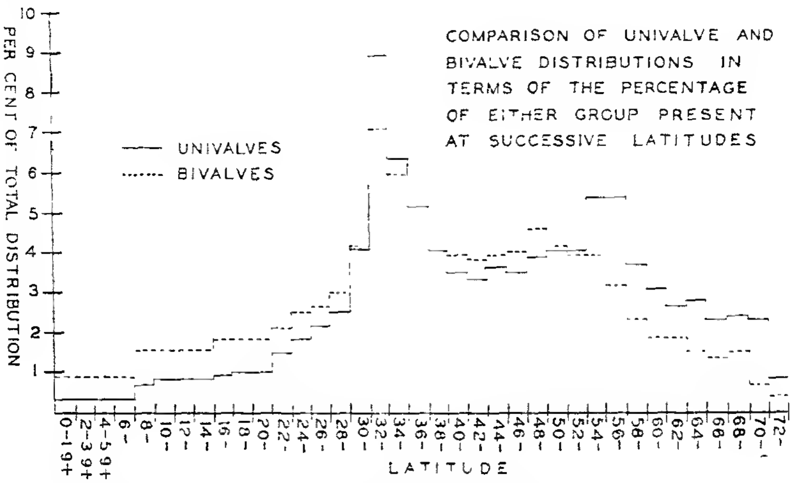

FIG. 3. Comparison of univalve and bivalve distributions in terms of the per cent of the total distribution of either group occurring at successive latitudes.

Method 2: Total Distribution.—A single curve only is given in figure 2, as the two component groups, bivalves and univalves, present very similar pictures. With the other two methods of analysis, however, the two groups are profoundly differentiated. Figure 3 is a comparison of the two in terms of their proportionate percentages of latitude-intervals. The diagram reads as follows: for univalves, nine per cent of the total number of latitude-intervals of range fall at 32°–33° north latitude, while only seven per cent for bivalves fall at this area; for the area 42°–43° North, the corresponding values are 3.6 per cent and 4.0 per cent, respectively, and so on. Statistically, the probability that the differences shown are purely chance is exceedingly remote, the difference between means being 14 times the probable error of difference.

There is a further difference between univalves and bivalves in width of range, the average bivalve ranging through an arc of 14.9 degrees of latitude and the average univalve

TABLE I

RELATIVE FREQUENCIES OF RECENT MOLLUSCA ALONG THE WEST COAST OF NORTH AMERICA

Pelecypoda

	Raw Frequency: No. at Latitude										Percentage Frequency: Per Cent of Total at Latitude									
	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74
25–29	177	174	104	62	52	41	21	7	7	5	37	36	22	13	11	9	4	1	1	1
30–34		325	200	137	123	100	63	20	16	14		68	42	29	25	21	13	4	3	3
35–39			229	154	145	109	70	21	19	17			48	32	30	23	15	4	4	4
40–44				159	147	113	75	22	20	19				33	31	24	16	5	4	4
45–49					185	146	102	43	36	32					39	31	21	9	8	7
50–54						167	113	48	41	37						35	24	10	9	8
55–59							140	59	50	44							30	12	10	9
60–64								71	54	48								15	11	10
65–69									55	48									12	10
70–74										48										10

Total No. = 477

Gastropoda and Scaphopoda

	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74
25–29	317	317	154	87	67	36	24	4	2	1	22	22	10	6	5	2	2	0.3	0.2	0.1
30–34		889	388	208	164	124	78	24	7	4		60	26	14	11	8	5	2	0.5	0.3
35–39			496	260	225	155	100	26	17	14			34	18	15	11	7	2	1	1
40–44				275	231	158	100	28	18	16				19	16	11	7	2	1	1
45–49					338	210	133	43	30	25					23	14	9	3	2	1
50–54						338	197	72	50	41						23	13	5	3	3
55–59							343	124	89	76							23	8	6	5
60–64								156	102	91								11	7	6
65–69									124	104									8	7
70–74										111										8

Total No. = 1471

through one of 9.2 degrees. Again the statistical possibility of chance as a causative factor is very remote—on the order of one in a million.

The two differences in distribution are shown in numerical form in table I, page 927, in which the area studied is divided into 10 segments each five degrees wide, and the number of species in each so tabulated that the number and percentage of species common to any two segments may be read. For example, 177 (or 37 per cent of all) species of pelecypods occur in the segment of coast between 25° and 29° 59′ north latitude; 48 (or 10 per cent) of pelecypods occur north of 70° north latitude; only five (or 1 per cent) range from the 25°–29° segment to and including 70° north latitude. The number of univalve species which are common to both of these segments is only one, or 1 10th of 1 per cent of the total.

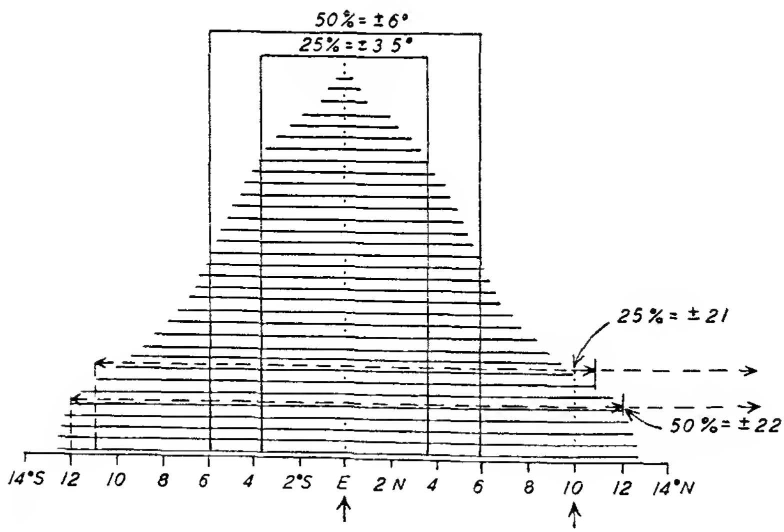

Fig. 4. Diagram of the relationships between ranges of species in a hypothetical faunal province.

Method 3: End-points of Range.—We must define an ideal province in order to explain the third method of analysis. Woodward, as previously stated, held that faunal provinces are areas in which fifty per cent of the species are unique.

We may utilize, as a basis of analysis, this general principle of uniqueness without attempting a decision as to the validity of the actual percentage. If the assumption is, simply, that a province is determined by the relative abundance of unique species, it follows that the center of the province will be composed in the main of relatively restricted species. Hence, the total length of range of those species occurring at the center will be very different from the total length of range of the species occurring at the border. This is illustrated in figure 4, a diagram of ranges in a hypothetical province the center of which is, let us say, at the equator. The latitudinal ranges of 32 species are shown here in the order of magnitude. Twenty-five per cent of the shortest ranges (i.e., the set ending with the eighth line from the top) are entirely included in a band 3.5 degrees of latitude on either side of the equator, or 7 degrees of latitude wide in all; fifty per cent of the ranges are included in a band $\pm$ 6 degrees on either side of the equator or 12 degrees wide, and so on. At a point 10° north of the equator, however, only 8 of the hypothetical species occur; to circumscribe the ranges of the most restricted twenty-five per cent of these, the band must be $\pm$ 21 degrees or 42 degrees wide (that is, the southward range from the point of reference is 21 degrees). We formulate the hypothesis from the above analysis that the width of range of an arbitrarily-chosen percentage of the species at any locality is an index of the relative distance of that point from a provincial center.

In figure 5, page 930, are shown such widths of range for the west North American area. The y-axis of the graph gives the latitudinal width of the stretch of coast line which will include the range limits of the most restricted 25 per cent of species occurring at each latitude-interval. Thus, at the latitude of Los Angeles (33°–34° N. Lat.), 25 per cent of the species of univalves range only one degree or less to the north or to the south. Twenty-five per cent of the bivalves are included within a band 2.3 degrees wide on either side of Los Angeles. At Cape Mendocino (41° N. Lat.), these bands

must be 8 degrees and 12 degrees wide on either side of the given latitude to include 25 per cent of univalves and bivalves, respectively, and so on.

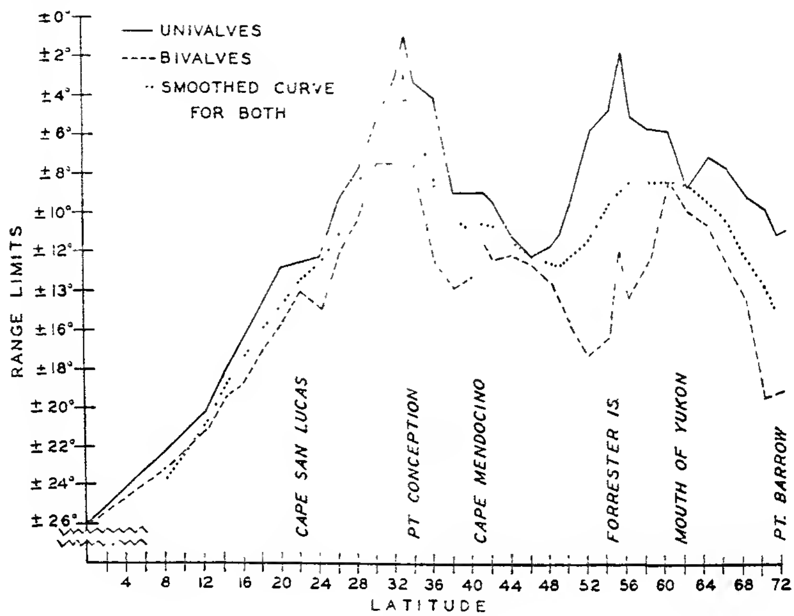

FIG. 5. Limits which completely circumscribe the shortest twenty-five per cent of ranges of the molluscan species occurring at alternate latitudes between 0° and 72° north latitude. Ideally, a faunal province has at its periphery wide-ranging species and at its center more narrowly-ranging species. The smoothed curve here seems to be an illustration of this principle.

The Los Angeles and the Forrester Island-Aleutian Island areas (Fig. 5) immediately stand out as areas of predominantly narrowly-ranging species, or, if our hypothesis is correct, as provincial centers. The Cape Mendocino area is, on the other hand, one of widely-ranging species, indicating it to be a provincial border. We must be cautious, however, in the drawing of sharp boundary lines, because of the marked differences in the bivalve and univalve distributions and because of the large Alaskan Gulf embayment. Either we must postulate separate provinces for the two classes of mollusks or compromise by drawing areal rather than linear boundaries, using the smoothed combination curve of figure

5 as an indicator of centers and determining the actual width of the areal boundaries by consulting figures 2 and 3.

Conclusions Concerning Provinces

Provincial boundary lines, as we conceive them, are shown in figure 6, where they are projected on a map of western North America and are compared with the boundaries proposed by some previous workers. The Arctic province apparently begins at the north with the southern limit of summer pack ice, at about 72° north latitude; it extends southward to latitude 58° North, but at the southern boundary overlaps the Aleutian province,[1] which extends northward to 62° North and southward to 42° north latitude. Between 48° and 42° North (Cape Flattery and Cape Mendocino), the Aleutian province overlaps the Californian. These overlaps, particularly the latter, are indicated in figure 2 by a secondary mode, and in figure 3 by the width of the trough between primary modes. Between Cape Flattery (48° N.) and Cape San Lucas (23° N.)—our Californian province—no distinct assemblages can be recognized *provided no attention is paid to bathymetric distribution.* If, however, shore collections or shallow dredgings alone were considered, a fairly sharp line of division would appear in the vicinity of Point Conception. We have little information on tropical or subtropical West American mollusks the ranges of which do not extend north to San Diego; hence, we can only tentatively indicate Cape San Lucas as the boundary. It may well be, particularly in view of the demonstrated areal boundaries to the north, that the Californian and Panamic provinces are separated by an overlap area, probably along the outer coast of Lower California. The entire Gulf of California falls in the Panamic province.

An incomplete list of species regarded as characteristic of the Arctic province includes *Yoldia oleacina* Dall, *Lora tenuilirata* (Dall), *Crepidula grandis* Middendorff, *Polinices*

[1] Exactly where the boundary line past the Aleutian Islands should be drawn we do not know, not so much because of lack of data as because of the anomalous conditions caused by the wide Alaskan Gulf with its tributary glacial streams.

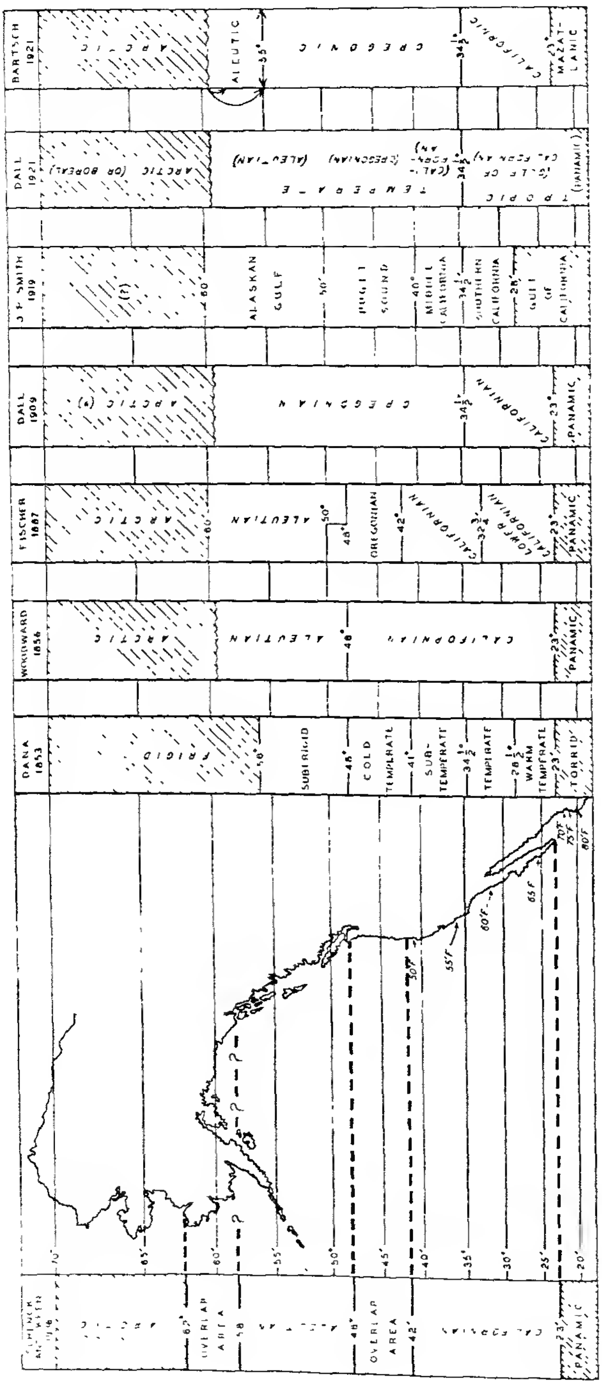

Fig. 6. Proposed boundaries of marine faunal provinces (left column), based on biometrical analyses of ranges of species, as compared with previously defined provinces of seven authorities (at the right). The general agreement among the authorities on the boundaries of the Arctic and Panamic provinces suggests that these are natural distribution areas. Disagreement on the intermediate boundaries is probably due to the attempt to draw sharp lines where none exist. Isotherms (from inshore observations) are from data supplied by G. F. McEwen.

pallida (Broderip and Sowerby), *Amauropsis purpurea* Dall, *Volutopsius beringi* (Middendorff), and *Beringius malleatus* (Dall).

Among the distinctive species of the Aleutian province are *Nuculana fossa* (Baird), *Yoldia seminuda* Dall, "*Pecten*" (*Patinopecten*) *caurinus* Gould, *Pandora grandis* Dall, *Lora solida* (Dall), *Chrysodomus pribiloffensis* Dall, *Buccinum castaneum* Dall, *Trophon scitulus* Dall, *Cerithiopsis truncata* Dall, *Littorina aleutica* Dall, and *Molleria quadrae* Dall.

Many species appear to be characteristic of the Californian province, among them being *Yoldia cooperii* Gabb, *Lyonsia haroldi* Dall, *Trachycardium* (*Dallocardia*) *quadragenarium* (Conrad), *Irus lamellifer* (Conrad), *Parapholas californica* (Conrad), *Macoma indentata* Carpenter, *Platyodon cancellatus* (Conrad), "*Lucina*" *californica* Conrad, *Saxidomus nuttalli* Conrad, *Acteon punctocoelata* (Carpenter), *Conus californicus* Hinds, *Mangelia angulata* Carpenter, *Olivella biplicata* (Sowerby), *Mitrella carinata* (Hinds), *Amphissa versicolor* Dall, "*Purpura*" *nuttallii* (Conrad), *Tritonalia gracillima* (Stearns), *Evalea io* (Dall and Bartsch), *Cerithiopsis cosmia* Bartsch, *Hipponix tumens* Carpenter, and *Tegula funebralis* (A. Adams).

Justification of Method of Analysis

It is a truism that no technique can compensate for unreliable data. One of the apparent defects of our data is that more careful collecting may extend many ranges. But, more precise work may also reduce the reported ranges of other species. The analysis, based as it is upon a very large number of species, cannot be markedly affected by occasional inaccuracies, since the errors must be compensating in part—southward extensions of some ranges being balanced by northward extensions of others. One notable northward extension was made by Keen, who collected during the summer of 1935, at Coos Bay, Oregon, a representative of the genus *Crassinella*.[1] This genus had not previously been reported north

[1] Stewart (*Acad. Nat. Sci. Philadelphia, Special Publ.* No. 3, 1930, p. 146) has overlooked the fact that Dall (*Jour. Conch.*, 4, April, 1883, p. 61) designated *Gouldia cerina* (C. B. Adams) as the type of *Gouldia*, thus making this name apply to a veneracean instead of to an astartid pelecypod.

of San Pedro, California. Four other significant northward extensions are recorded by MacGinitie (1935, p. 658).

Collecting along the west coast of North America has not been uniform. Therefore, it is possible that areas which appear to be "centers" may be merely areas of intensive collecting. For the San Pedro center this may be true, but it is not a sufficient explanation of the dominance of the Forrester Island-Kodiak Island area over the better-worked Puget Sound region. Forrester Island contributes some 138 unique species (i.e., species restricted to the area), the Aleutian Islands 121, Puget Sound only 65. On the other hand, Monterey Bay, an area of repeated collection over a long period of time, does not by any mode of analysis appear dominant.

The factor of classification must not be neglected. It may be, for example, that many truly autochthonous species are masquerading under exotic names. This, fortunately, would have no effect upon the present results, since we are considering only the reported ranges of the species on the western North American coast. But differences between major groups (families) in speciation and particularly in the thoroughness of study which they have received might have some effect upon our results, especially if ranges in those groups happened to be concentrated in one or two restricted areas. An example of this sort is the concentration of Buccinidæ and Turridæ in the Aleutian area. Unless these and like groups constituted the majority of species included in the study (actually they comprise but one-sixth of the total fauna), the only effect they would have would be an exaggeration of the peaks or troughs of the curves. Fineness of division of one group as combined with coarseness of division of some other groups would have the same kind of effect, an exaggeration but scarcely a serious skewing of the profiles we have obtained.

Taxonomic revision may, of course, appreciably alter the number of species recognized in certain groups. The genus *Acmæa* is probably an extreme example, the check-list (Dall,

1921) containing 33 species and subspecies, only 24 of which appear to be valid.

Bathymetric distribution is necessarily neglected here, since little exact work has been done. It is possible that systematic dredgings along the coast, together with a careful recording of bottom conditions, might profoundly alter not only the present conclusions, but also many of the dogmas current today concerning distribution.

These are the principal defects in our study. In every case they prove to be of data rather than of method. Thus, the accumulation of more precise data will not necessarily invalidate our technique, even though the actual conclusions must be modified later. In defense of the biometrical analysis employed may be cited the remarkable internal consistency, in that the three methods of analysis, though based upon different aspects of distribution, all point to the same general conclusions concerning provinces.

Actuality of the Molluscan Provinces

Since we must admit that our data are defective, we leave open the possibility that the molluscan provinces here recognized are fictitious. Confirmation of our conclusions, however, is indicated by the distribution of other marine organisms. Inspection of the reports on nine other biologic groups, made by various workers, shows that of the nine,[1] five groups (foraminifers, corals, sea stars, annelid worms, and decapod crustaceans) confirm the existence of a provincial boundary at or near Cape San Lucas; three (foraminifers, echini, and decapod crustaceans) show so little differentiation as to seem but a single faunal group between Alaska and Cape San Lucas; two (hydroids and annelid worms) are in almost complete accord with the Mollusca; and one (pteropods) shows a faunal break near our Aleutian-Californian boundary.

[1] 1. Foraminifers, Lois Martin (MS.); 2. Sponges, M. W. de Laubenfels (1929); 3. Corals, L. Joubin (1912); 4. Hydroids, H. B. Torrey (1902, pp. 5–6); 5. Sea stars, W. K. Fisher (MS., written communication); 6. Echini, A. Agassiz (1872); 7. Annelid worms, C. Essenberg (1918); 8. Decapod crustaceans, W. Schmitt (1921); 9. Pteropods, R. Rutsch (1934).

On the whole, then, confirmation rather than contradiction is the rule.

Date of Establishment of Provinces

The exact time of the establishment of the modern provinces, in their broader outlines, is not known. The presence in Eocene strata of genera today restricted to equatorial belts, supplemented by evidence from paleobotany and fossil mammals, has led to the deduction that tropical conditions existed during most, if not all, of the Eocene epoch from the equator to at least the latitude of Puget Sound, and perhaps farther north. Granting this, we assume that the blocking-out of the present marine molluscan provinces took place after the Eocene. Suppose that during the late Oligocene or early Miocene northern and southern marine temperature conditions were established. This would account for the difficulty in discerning any faunal relationship, employing only the Mollusca, between the so-called Vaqueros formation of California and the Blakeley formation (in whole or in part) of Washington, a relationship which is indicated by the Foraminifera of the two formations. Tropical seas did not extend north of southern California during the late Miocene. Therefore, we conclude that the West American molluscan provinces were, in their general outlines, established sometime during the Miocene.

Summary

This investigation is a statistical treatment of available data on the distribution of West North American marine Mollusca. The ranges of 1,948 species, as given by Dall (1921) in U. S. National Museum Bulletin 112, supplemented by known extensions of range, are analyzed in three ways: (1) according to mid-points of range; (2) according to total distribution; (3) according to the relative spread-of-range about certain points of reference (alternate latitudes).

We define a province as an area containing a distinctive assemblage of species; according to this criterion, the following areas are indicated by our data: The Panamic province

(the southernmost of our provinces) has its northern limit at about latitude 23° North. The Californian province extends from 23° northward to latitude 42°. Between latitudes 42° and 48° North there is an overlap area, succeeded to the north by the Aleutian province to latitude 58° North. Next comes another overlap area to latitude 62° North, beyond which extends the Arctic province.

In this report we have shown not only that the tenuous division-lines recognized by previous workers are overlap areas, but also that by biometrical methods their widths can be measured. Further, we have shown that within a single class of organisms profound differences in range occur, as in the differential distribution of bivalves and univalves; this difference, however, does not invalidate either the concept of provinces or the statistical method for their derivation. The provinces in their broader outlines are of appreciable age, having apparently been established during the Miocene epoch. We conclude, since all available evidence points in this direction, that marine molluscan provinces have an objective reality.

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THOMAS JEFFERSON'S GARDEN BOOK

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Abstract

Thomas Jefferson kept a memorandum book about doings in his gardens from 1766, after his return from William and Mary College, to 1824, when he was 58 years of age. This book contains jottings of interest because of the author and because of the relation they bear to matters with which Jefferson was associated, or in which he was interested.

Notes on the ornamentals and on garden vegetables are accompanied by observations on the weather, by information on plant introductions from other parts of the world, and by notes bearing on items of wider public interest, as (1) grape growing in reference to the temperance movement, (2) the introduction of upland rice to ameliorate conditions connected with the growing of that crop, (3) the possible utility of plants brought back by the Lewis and Clark Expedition.

Interesting light is thrown on the details of matters connected with the writer, in relation to landscape problems, methods of work, quantities of material used, and other practical affairs.

Occasional references in works on the life and activities of Thomas Jefferson mention a memorandum book kept for many years dealing with his gardens. In view of the fact that he was intimately concerned with many matters having scientific as well as more definitely practical significance, it seemed to me desirable that this record should be found and studied. Accordingly, when some years ago this manuscript was found in the library of the Massachusetts Historical Society, it was hoped that a study might reveal material that would throw light on another of the many lines of interest maintained by one of the most remarkably diversified minds this country has known.

The book is hardly a diary, since notes are often scarce, and are unevenly scattered through the year, while during long periods of time, as when Jefferson was living in Philadelphia and in Paris, there is an entire lack of notes. The same record book served him from 1766, when as a young man he came back from William and Mary to the parental home, Shadwell, to 1824, two years before his death—58 years in all.

The notes throughout are in Jefferson's own handwriting, and offer an interesting series of samples showing the changes with the years.

The subjects seeming to him worth noting are usually commonplace, and the entries probably grew in some measure out of the note-taking habit of a man industrious with his pen throughout his active life. At times, however, observations are included that hint at other and more significant things. His first annotation is one of the less usual observations bearing on the esthetic interest of the subject. On March 30, 1766, he writes: "Purple hyacinth begins to bloom." During the following spring months, narcissus, puckoon, the purple flag, violets, and honeysuckles, are noted, as well as "a bluish colored, funnel-formed flower in low grounds." He notes the times of coming into bloom, and the end of the flowering periods. These wild plants here share interest with garden varieties.

Notes made in 1767 are more numerous and diversified. A large number of sorts of old-fashioned flowers are noted, usually with the time of blooming, but the vegetable garden claims more lines than the ornamentals. In February, he is sowing two kinds of garden peas, the progress of which is followed until the earlier lot "comes to the table" on April 24th. Apparently, while dealing with the pea seeds to be planted, a curious and steadily present inclination to statistical precision first appears. A line records that "500 of these peas weighed 3 ozs., 18 pwt., about 2500 fill a pint." This type of accurate dealing crops out often and records, apparently for later reference, facts that may be useful in future planning. One can here learn how long it took Jefferson's seeds of celery, asparagus, peas, Spanish onions, and lettuce, to come up and to become useful.

The flowering times of Sweet William, lunaria, snapdragon, lychnis, larkspur and poppies, are recorded, facts of interest to one designing a flower garden. He looks further ahead and plants trees and shrubs, lilacs, roses, laurel, Spanish broom, plums and gooseberries, almonds and altheas.

Strawberries planted in 1766 now bear for the first time, and again, Jefferson becomes statistical. "The plants bear 2 o. strawberries each, 100 fill half a pint." This bit of information shows how this fruit has been increased in size through the skill of gardeners since his time.

The book now begins to be a repository for occasional records of importance in the economy of a plantation; *e.g.*, "8 or 10 bundles of fodder (corn RHT) are as much as a horse will generally eat through the night; 9 bundles × 130 days = 1170 for the winter."

In 1768, his records are brief and confined to the spring months. Again peas are counted, Charlton Hotspur—"500 of these peas weighed 3 ozs., 7 pwt., 2000 filled a pint accurately."

With 1769 his notes begin to concern Monticello entirely, his new home growing on the height above Charlottesville. With March 14th, planting begins, trees and shrubs receiving exclusive attention; pears, one row of them grafted, cherries, New York apples, peach stocks, nectarines, quinces, pomegranates, figs, walnuts and apricots, being enumerated.

Notes on the quantity of lime to lay 2000 bricks indicate the beginning of construction, either on the house or walls about the place. He notes what Nicholas Meriweather says about the area needed to produce watermelons enough for a family "not very large." He quotes Miller's Gardener's Dictionary on the yielding capacity of 50 hills of cucumbers, "1 hill yields 40 cucumbers."

In 1771, notes on weather conditions begin to enter, and record items that seem to sound like the weather reports of today.

I have quoted these items to show the character of much of the content of this Garden Book, and rather commonplace the material seems to be. However, certain entries are connected with matters not mentioned, and hint at subjects of wider interest.

In 1771, Jefferson makes a note of shrubs not exceeding 10 feet in height, in great part native plants. Another list

of trees is recorded, in part native, including dogwood, red birch, catalpa, magnolia, mulberry and locust among the number. Other lists of climbing shrubs, evergreens and hardy perennials follow. This seems to be a mustering of materials to be considered in his plans for planting his grounds.

Next year, he married Martha Skelton and brought her home to the partly finished house and unfinished surroundings.

In that year, 1772, there was much activity on the little mountain. Earth was being moved, walls were being laid, and the new road up the mountain was being built. Here again, the statistical method applied to the task suggests the modern efficiency expert. "Julius Shard fills the two-wheeled barrow in 3 minutes and carries it 30 yards in $1\frac{1}{2}$ minutes more. Now this is four loads of the common barrow with one wheel. So that suppose the 4 loads put in, in the same time, viz., 3 minutes, 4 trips will take $4 \times 1\frac{1}{2}$ minutes—6, which added to 3 filling is—9 to fill and carry the same earth which was filled and carried in the two-wheeled barrow in $4\frac{1}{2}$ minutes. From a trial I made with the same two-wheeled barrow, I found that a man would dig and carry to the distance of 50 yards, 5 cubical yards of earth in a day of 12 hours' length. Ford's Phill did it, not overlooked, and having to mount his loaded barrow up a bank 2 feet high and tolerably steep." This sample may illustrate the type of observation and annotation frequently occurring before 1809. After that date, the material is generally compactly tabulated, and extended notes are unusual.

In 1773, he continues to plant fruit trees, while grape vines and a few notes on wine appear.

An interesting light is thrown on the domestic arrangements on a large plantation by a list of "articles for contracts with overseers."

"He (the overseer RHT) shall let his employer have his share of grain if he chooses it at a fixed rate.

"He shall not have his share until enough is taken out to sow, and then only of what is sold or eaten by measure.

"Allow $\frac{1}{2}$ a share for every horse and same for a plough-boy.

"To have at the rate of a share for every 8 hands, but never to have more than 2 shares if there be ever so many hands.

"Provision 400 lbs. pork if single, 500 lbs. if married."

"To be turned off at any time of the year if employer disapproves of his conduct, on paying a proportion of what shall be made, according to the time he has staid.

"To pay for carrying his share of the crop to market.

"To pay for carriage of all refused tobo (tobacco RHT).

"To pay his own levies.

"To pay his share of liquor and hiring at harvest and never bleed a negro."

In 1774, the book begins to show traces of an activity that grew with Jefferson and became a matter of public interest. His Garden Book shows a long series of entries in Italian, apparently growing out of a shipment of garden seeds from Mazzei, who had gone to Europe on a governmental errand. This list was a long one, and introduced a variety of onions, endive, parsley, spinach, broccoli, radishes, bush fruits, melons, cantaloupes, squashes and grapes. The grapes were planted by "some Tuscan vignerons who came over with Mr. Mazzei."

Jefferson's interest in grape growing and in wine making as an American industry is here indicated. That interest grew as the devastating effects of drinks having a high alcoholic content were realized. He looked on the domestic making of pure wine for family consumption or the use of cheap imported French wines as temperance measures. His agreement with Timothy Pickering on these matters throws an interesting light on Jefferson's concern for genuine public welfare and his idea of the type of remedy to be applied.

After recording in full how the Tuscan vignerons planted the grapes, he records unusual weather conditions, effects of the destructive frosts of May being given in some detail.

In 1775, again he records destructive frosts in the spring, but little else is recorded.

No records appear in 1776, for reasons that are easily understood.

I will pass over the remaining years, in which the usual

types of items are found. To the plant student, much of interest is to be found in Jefferson's notes. The dates of the appearance of a great variety of imported plants and trees are historically interesting, the result of Jefferson's desire to introduce the best products of the Old World into the young country. He was equally concerned to see what might be done with the native plants.

His efforts to establish the growing of upland rice in America grew out of his realization of the loss of health and of life in the malarial rice fields of Carolina. He had ship captains sailing to other lands enlisted as observers and agents. Seeds of upland rice were brought from the Pacific islands and from Asia, and he himself visited the Italian regions growing dry rice, and started an active local cultivation from a little of the seed that he brought home in his pocket. Upland rice did not displace that of the wet lands until long after Jefferson's day, but small areas of these early sorts are still grown in the Georgia mountains.

The Garden Book records: "May 7, 1810, sowed upland rice at the mouth of the meadow branch."

In 1794, Jefferson was planting sugar maples at Monticello in the hope of using them as a source of sweetening. He frequently urged the possible value of this tree for this purpose. In the same year he was planting pecans, that later he seems to have distributed to Washington, Judge Duval, and others. He was again trying to develop the use of a native product.

In 1794, he was quoting temperatures observed on Doctor Walker's thermometer, he himself lacking one. By 1803, he seems to have supplied the missing instrument, since he is quoting temperatures freely.

I know of no earlier planting of a nursery of forest trees in this country than that of Jefferson on April 12, 1804, when he planted hemlock and white pine "near the aspen thicket." Grapes, pecans, and fruit trees continue to furnish main items at this period, with minor plantings of a great number of garden plants from foreign lands. Monticello had become an

actively operated experiment station, where plants from all corners of the earth were planted and tested.

References in the records of the Lewis & Clark Expedition to seeds brought back from the west gave rise to a search into the subsequent history of those seeds. The results of that search were reported some years ago to this Society. The Garden Book shows that a few of these seeds were taken to Monticello, where Jefferson put them into his experimental garden. "Pani corn," noted in 1811, was planted with native Cherokee corn, with Quarantine corn from his friend Thouin at the head of the Jardin des Plantes in Paris. "Columbian salsify," one of the Lewis & Clark plants of the far west, having a fleshy root, was grown and tested on the table at Monticello. The verdict was adverse.

In 1812, more of the Lewis & Clark material appeared at Monticello. Red gooseberry, Lewis' sweet-scented currant, Lewis' snowberry bush, and Lewis' yellow currant indicate the propagation of a group of ornamental shrubs, several of which in time took an established place in ornamental planting.

He sums up his long experience with plants at Monticello in 1823, as his life neared its close, in a condensed table of what should be done month by month. He calls it "Compend of a Calendar."

As time passes, and the nation goes through its strenuous earlier years, the Garden Book of Jefferson continues to tell a quiet story of grapes and sea kale for the garden, of carp and chub for the fishpond, of plums and peaches, peas, radishes and squashes, and one can understand his longing to leave the man-made tumult of Philadelphia and Washington. The worn Garden Book seems to give a glimpse into the background of the life of one of the most significant and storm-tossed characters in our history, and in this close contact with plants and with the earth, we seem to find one of the real sources of his strength.

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